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IMPROVED MANEUVER CRITERIA EVALUATION PROGRAM

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Fort Eustis, Va. 23604

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report has been reviewed by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), and is considered to be technically sound. The purpose of the program documented here was to improve the digital maneuver simulation method, MCEP, to include the capability to vary rotor rpm for selected maneuvers, provide a terrain avoidance maneuver and produce speed power polars. In addition, the program includes better diagnostics and user conveniences and a plot routine for graphic displays.

Messrs. William A. Decker and Robert P. Smith of the Aeronautical Technology Division, Aeromechanics Technical Area, served as Project Engineer and Assistant Project Engineer, respectively, for this effort.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Maneuver Criteria Evaluation Program (MCEP) is a digital computer program that solves the flight path equation of motion for a helicopter without auxiliary propulsion. The use of basic work, energy, and power relationships makes possible accurate representation of flight path trajectories. MCEP can be used to aid in the development of maneuver requirements

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that provide the necessary maneuver capability to perform the desired mission. The desired mission is simulated in MCEP by using individual flight controllers to "fly" the helicopter through the mission profile. Key maneuver parameters are monitored throughout the flight profile to provide insight into the performance of the helicopter in achieving the desired flight trajectory.

Three maneuvers have been modified to allow rotor rpm to be bled to use some of the rotor's stored energy. These maneuvers are a constant altitude acceleration maneuver, a collective pop-up maneuver, and a sideward acceleration maneuver. Correlation with flight test data is established to validate the bleed rpm maneuvers.

The appendix to the report, the User's Guide, contains the detailed information necessary for setting up an input data deck for MCEP.

<u>PREFACE</u>

This report and its accompanying computer program were developed under Contract DAAJ02-76-C-0064, "Increased Aircraft Agility with High Energy Rotor System," awarded in September 1976 by the Eustis Directorate of the U.S. Army Air Mobility Research and Development Laboratory.

This report is an addendum to the original work published under USAAMRDL-TR-74-32, Maneuver Criteria Evaluation Program.

782209

Technical program direction was provided by Mr. W. A. Decker.

Principal Bell Helicopter Textron personnel associated with the contract were Messrs. D. Yeary, T. Waak, and T. Wood.

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INTRODUCTION

The original maneuvers developed for the Maneuver Criteria Evaluation Program (MCEP) were constrained to be constant rotor rpm. As a result of this restriction, the benefits of using some of the rotor's stored energy through bleeding rotor rpm could not be investigated. Three maneuvers have been modified to allow the rotor rpm to be bled to use some of the rotor's stored energy. These maneuvers are a constant altitude acceleration maneuver, a collective pop-up maneuver, and a sideward acceleration maneuver. These specific maneuvers are the only ones allowed to have variable rotor rpm. These maneuvers were modified in a manner consistent with the energy method used for the other maneuvers. Correlation with flight test data is established to validate the bleed rpm maneuvers.

Several modifications to the original program have been made based on user comments. Appropriate diagnostic messages have been added to MCEP to aid the user in analyzing the reason for any program stops. The capability to sweep any input parameter without reading the input data deck again has been added.

In addition to the above features, two additional maneuvers have been provided to allow more utilization of the MCEP. One maneuver generates speed power polars using the input data. This maneuver allows power correlation to be determined prior to any evaluation. The second maneuver allows determination of flight profile for pullups or pushovers for specified load factor inputs. Another feature provided is a plot routine. The program can generate a plot tape for Calcomp plots. These plots can be used for graphic displays of the profiles flown. The above features were developed by BHT as a result of internal use of the MCEP.

DESCRIPTION OF MODIFICATIONS TO MATHEMATICAL MODEL

The computation of flight trajectories of a helicopter in the MCEP is based on the energy method for predicting helicopter maneuverability. This fundamental method uses the concepts of work and energy to predict the helicopter's ability to change its direction of flight. The helicopter is flown by controlling the linear accelerations in the wind axes.

GROUND EFFECT MODEL

In the original MCEP ground effect is not considered. However, for correlation work it became necessary to add a representation of ground effect to the math model.

The following empirical method has been added. The power required is adjusted as a function of the helicopter's rotor height above the ground as given in Reference 1 and expressed as

$$\frac{K}{K_\infty} = \frac{1}{GEFFZA + GEFFZB\left(\frac{1}{Z/D}\right)^2} \qquad (1)$$

where D = main rotor diameter
Z = height of the main rotor hub above the ground

This height, Z, is computed using

$$Z = H + SKTPCA \qquad (2)$$

where H = skid or wheel height above the ground

SKTPCA = height from bottom of landing gear to main rotor blade pitch change axis

The sign of SKTPCA determines whether the ratio of K/K_∞ is applied to the induced horsepower or to the total horsepower. If SKTPCA >0, the ratio of K/K_∞ is applied to the induced horsepower. If SKTPCA <0, the ratio of K/K_∞ is applied to the total horsepower. The choice of the coefficients in Equation (1) depends on whether induced or total horsepower is being modified. If GEFFZA and GEFFZB are specified to be zero or 1, the program will default to GEFFZA=0.9926 and GEFFZB=0.03794.

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[1] Hayden, James S., THE EFFECT OF THE GROUND ON HELICOPTER HOVERING POWER REQUIRED, 32nd Annual National V/STOL Forum of the American Helicopter Society, Washington, D.C., May 1976.

These values come from Reference 1 and are intended to operate on induced power. Therefore, the value of SKTPCA should be assigned a positive value. If SKTPCA is set to zero, the ground effect model is disabled.

Ground effect ratio is limited to a maximum value of 1 and is washed out with airspeed as follows:

$$\frac{K}{K_\infty} = 1, \text{ if } \frac{V_{horz}}{40} \geqslant 1 \qquad (3)$$

$$\frac{K}{K_\infty} = \frac{1}{GEFFZA + GEFFZB\left(\frac{1}{Z/D}\right)^2} + \left[1 - \frac{1}{GEFFZA + GEFFZB\left(\frac{1}{Z/D}\right)^2}\right]\frac{V_{horz}}{40},$$

$$\text{if } \frac{V_{horz}}{40} < 1$$

where $V_{horz} = \sqrt{V^2 - V_{ZE}^2}$

V_{horz} = horizontal velocity

V = airspeed along flight path

V_{ZE} = component of velocity in ZE direction

Ground effect is washed out for velocities over 40 knots.

ROTOR ENERGY

The energy stored in the rotor is

$$E = 0.5(IR)\Omega^2 \qquad (4)$$

where IR = rotational inertia of the rotor system

Ω = rotational speed of the rotor

Then, power is the first derivative of Equation (4)

$$P = \frac{\partial E}{\partial t} = (IR)\Omega\dot{\Omega} \qquad (5)$$

where $\dot{\Omega}$ = rate of change of Ω with time

From Equation (5) power can be extracted from the rotor by creating a bleed rate ($\dot{\Omega}$). For the constant rpm case, the horsepower available (HPA) is simply that provided by the engine (HPENG). For the bleed rpm case, the horsepower available is

$$HPA = HPENG - \frac{(KR)(IR)\Omega\dot{\Omega}}{550} \qquad (6)$$

where KR = energy efficiency factor

The change in rotor rpm is computed as follows:

$$\Omega = \Omega + \dot{\Omega}\ dt \qquad (7)$$

As the rpm drops, the torque on the transmission will increase if the engine power remains the same. It is important to understand that the power produced in the rotor does not increase mast torque. The only increase in mast torque comes from a drop in rpm while maintaining the same engine power. To prevent overtorquing the transmission, the engine power will be reduced in a maneuver if the torque is greater than the maximum allowable transmission torque. The engine power will be reduced by the following increment:

$$\Delta HPENG = \frac{(Q - Q_{max})\Omega}{550} \qquad (8)$$

where Q = torque at instantaneous value of rpm

Q_{max} = maximum transmission torque

DESCRIPTION OF NEW MCEP MANEUVERS

The maneuver Criteria Evaluation Program has been expanded to include the following maneuvers. The capability and function of each of the new MCEP maneuvers are reviewed. The assumptions made in the formulation of each maneuver are discussed and the input requirements are listed.

ACCELERATION AT CONSTANT ALTITUDE USING BLEED RPM

The bleed rpm acceleration controller flies the aircraft to a velocity that is within the specified error band of the commanded velocity. Engine power is augmented by the power extracted from the rotor while bleeding rotor rpm. This maneuver can be used in mission simulation to increase the velocity of the aircraft while maintaining constant altitude and using some of the rotor's stored energy.

This maneuver has four phases. The initial phase has the same control logic as the acceleration/deceleration at constant altitude maneuver. As engine power is increased to the maximum value, Equations (82) and (83), Reference 2, are used to compute the longitudinal acceleration. Once engine topping power is reached, the rpm bleed phase is initiated. The rpm bleed rate is input data and up to four bleed rates can be used. The rpm bleed rate (OMGBD1) and the rotor rpm breakpoint for changing bleed rate (OMGBL2) are used to determine the bleed rate and the rpm range over which that bleed rate is used. If the rotor rpm breakpoint (OMGBL2) is less than the minimum rotor rpm (OMEGMN), then the rpm bleed rate (OMGBD1) will be the only bleed rate used. If OMGBL2 > OMEGMN and OMGBD2 is zero, the bleed rate will stop when OMGBL2 is reached. During the rpm bleed phase, horsepower available (HPA) is modified to include power from the rotor due to bleeding of rotor rpm.

$$HPA = HPENG - HPRPM \tag{9}$$

$$HPRPM = \frac{(KR)(IR)\Omega\dot{\Omega}}{550} \tag{10}$$

[2]Wood, T.L., Ford, D. G., and Brigman, G. H., Bell Helicopter Company; MANEUVER CRITERIA EVALUATION PROGRAM, USAAMRDL Technical Report 74-32, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1974, AD 782209.

where

HPC = maximum engine power to be applied
HPLTM = transmission power rating at normal rpm
HPENG = minimum of HPC and HPLTM
KR = energy efficiency factor
Ω = current rotational speed
$\dot{\Omega}$ = rate of change of rotational speed with respect to time
IR = rotor inertia

The next phase of the maneuver is entered when the rpm drops to the minimum. The acceleration maneuver is continued at the reduced rotor rpm until it is time to reduce the acceleration to reach the commanded velocity or the acceleration becomes less than 0.05 ft/sec^2. This part of the logic is the same as the constant rpm maneuver. Two additional options are provided in this phase. A time (TPRMMN) can be specified to remain at the minimum rpm before starting recovery independent of the velocity or commanded velocity (VC). A minimum velocity (VMNREC) can be specified that represents the velocity at which rpm recovery is to be initiated. If VMNREC > VC, then the maneuver will proceed as though the value of VMNREC = 0. If VMNREC and TRPMMN = 0, the control logic proceeds as the normal maneuver does.

After the controller has started reducing the acceleration by reducing power to arrive at the command velocity, the rpm recovery phase is initiated. Up to four rpm recovery rates (OMGRD1) can be specified along with the rotor rpm breakpoints (OMGRC2) for changing the recovery rates. The power required to achieve the specified rpm recovery rate is computed by Equation (10).

The maximum engine power that can be used at the current rpm is computed from the maximum transmission torque allowed. If engine power available exceeds this value, then engine power is reduced to the maximum transmission torque value. The value of engine power required to maintain flight at the current value of acceleration along with the increment in engine power required to achieve the rpm recovery rate is compared to the engine power available. If the power required is less than the power available, the rpm is recovered at the desired rate. If not, then the rpm recovery rate is reduced to the maximum value possible with the excess engine power available. The aircraft may be at its commanded velocity while the rpm is still less than normal value. In this situation, the rpm will be recovered to the normal value prior to ending the maneuver. If OMGRD1=0, then rpm will be recovered at the maximum rate possible with available engine power.

An example of this maneuver is shown in Figure 1. The input requirements are command velocity, velocity error band, maneuver urgency factor, minimum power setting, maximum power setting, blade inertia, main rotor transmission rating, energy efficiency factor, minimum rotor rpm, time interval to accelerate at minimum rpm velocity at which rotor rpm recovery is initiated, four bleed rates of rotor rpm, four rotor rpm breakpoints, four recovery rates of rotor rpm, and four rotor rpm breakpoints.

COLLECTIVE POP-UP USING BLEED RPM AT CONSTANT ATTITUDE AND LOW AIRSPEED

The bleed rpm collective pop-up controller changes the altitude of the aircraft while maintaining constant attitude. The rate of climb is increased from the use of some of the rotor's stored energy. This energy is used by bleeding rotor rpm. The ground speed is constant during the maneuver. This maneuver can be used in evaluating low-speed tactics.

The controller flies this maneuver at maximum power available and determines the maximum load factor that can be achieved using maximum power for the given flight condition. The load factor reaches NMAX in time tpn as defined by Equation (123) of Reference 2. This portion of the maneuver is unchanged from the constant rpm maneuvers.

The controller then maintains load factor at the determined value, which requires maximum horsepower available. Once NMAX is reached, the rpm bleed begins. The increment in HPA is calculated by Equation (1) and added to the engine power available. This increment in power allows a higher acceleration to be sustained and thus an increase in rate of climb results. As rpm is decreased, the engine power is compared to the transmission torque to ensure that the transmission is not being overtorqued. If the engine power available exceeds the transmission torque limits, the engine power is reduced accordingly. The bleed rate of rotor rpm is OMGBD1 and the rotor rpm breakpoint for changing bleed rate is OMGBL2. Four values of bleed rates and rpm breakpoints may be specified.

The helicopter will climb at minimum rotor rpm and either the minimum of maximum engine power or maximum transmission torque limit until the controller initiates recovery to arrive at the desired altitude. If the controller initiates recovery prior to reaching minimum rotor rpm, the rotor rpm recovery phase will be initiated. The controller used the same logic for both the constant rpm and bleed rpm maneuvers to arrest the climb rate to arrive at the desired altitude. As the load

MCEP INPUT

VCP =60	PSU = 1	EEF = 1	OMGBD1=2	OMGBD3=0	OMGRC2=0
VERR= 2	MPRINT= 1	OMEGMN=300	OMGBL2=4	OMGBL4=0	OMGRD2=0
MUF = 1	BINERT=2860	TRPMMN= 0	OMGBD2=0	OMGBD4=0	OMGRC3=0
PSL = 0.5	HPMAXT=1200	VMNREC= 0	OMGBL3=0	OMGRD1=4	OMGRC4=0

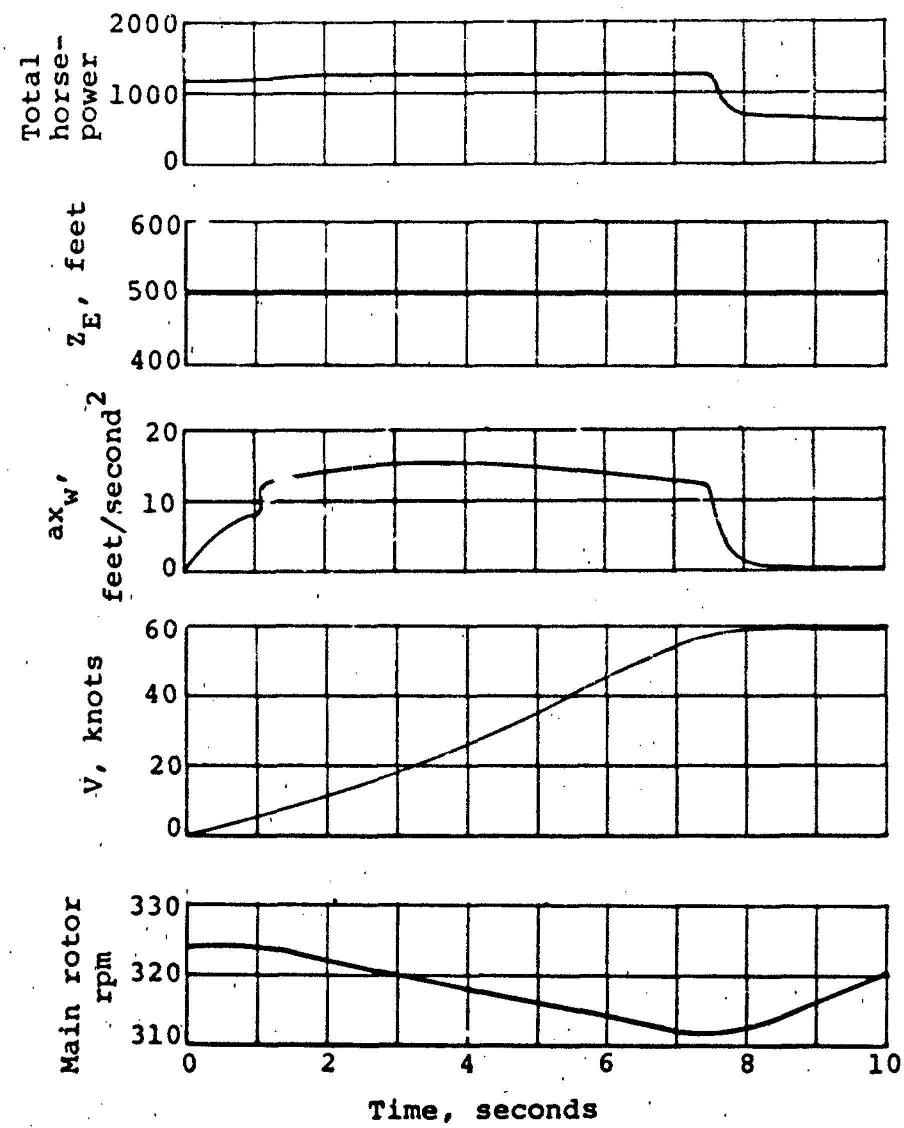

Figure 1. Time history of accele-ation using bleed rpm maneuver for AH-1G helicopter at 9500 pounds.

factor is reduced according to Equations (124) and (125), Reference 2, excess engine power becomes available. This excess engine power can be used to recover the rotor rpm. The maximum recorvery rate of rotor rpm is calculated from

$$\Omega MAX = \frac{550\ (HP_{EXCESS})}{(KR)(IR)\Omega} \tag{11}$$

where

HP_{EXCESS} = minimum HPEMAX or HPTMAT

HPEMAX = maximum engine power available

HPTMAX = maximum power limit of transmission at current rpm

The input values of recovery rate of rotor rpm (OMGRD1) are compared to the maximum recovery rate possible from Equation (11). The minimum value of these two rates is used. If the recovery rate is input as zero, $\dot{\Omega}$MAX is used to recover the rpm to the normal value of rotor rpm. The rpm recovery continues until the normal rpm is reached. The full recovery may be prior to arriving at the desired altitude or after stabilizing at the desired altitude.

With the use of the additional power from the rotor, it is possible to climb to altitudes from an in-ground-effect hover when insufficient power is available to maintain stabilized hover out-of-ground effect. During the climb, the controller monitors the total power available and the power required. As power required approaches power available, the load factor is reduced and the climb rate (V_{ZE}) is reduced. As power required exceeds power available, the controller sets up a rate of descent. After V_{ZE} changes sign, rpm recovery is initiated. The rate of descent is determined from the excess power required to recover the rotor rpm at the input value of recovery rate of rotor rpm.

The controller controls the maneuver through reducing load factor. If the load factor required to establish sufficient excess power to accomplish the input recovery rate is less than the input value of minimum load factor (NMIN), then the recovery rate possible with the excess power from pushing over at NMIN is used. If the specified recovery rate (OMGRD1) is zero, the recovery rate defaults to 1 rpm per second. If the rpm is recovered fully prior to the command to initiate pullout at the initial altitude, the controller will check to see if it is possible to hover at the current altitude. If so,

then the controller will arrest the sink and stabilize at an intermediate altitude. The maximum load factor allowed during arrestment of the sink rate is the input value NMAXDV. The pullout is accomplished using equations (124) and (125), Reference 2, with the exception of using NMAXDV instead of NMIN. If the altitude is stabilized at the starting altitude before the rpm is recovered fully, then rpm recovery continues until normal rpm is established.

The input requirements for this maneuver are the commanded altitude, maneuver urgency factor, minimum load factor, maximum power setting, blade inertia, main rotor transmission rating, energy efficiency factor, minimum rpm, maximum load factor, the initial bleed rate, three pair of rpm bleed rates and rpm breakpoints, the initial recovery rate, and three pair of rpm recovery rates and rpm breakpoints. An example of this maneuver is shown in Figure 2.

SIDEWARD ACCELERATION USING BLEED RPM/PEDAL TURN INTO WIND

The bleed rpm sideward acceleration/pedal turn into wind controller accelerates the aircraft to the right or left from a hover at constant altitude while the nose of the aircraft is tracking a target. The aircraft is accelerated until the commanded sideward velocity is established. The additional power from the main rotor from bleeding rpm allows higher accelerations. Then the aircraft stops tracking and swings its nose into the wind. This maneuver can be used to evaluate sideward acceleration in conjunction with other maneuvers.

This maneuver is controlled by the bank angle that the aircraft maintains in the acceleration phase of the maneuver. The limiting factor in this maneuver is the power available. The maximum bank angle attainable is computed from an estimate of the power available as follows

$$HPA = HPENG - \frac{(KR)(IR)(\Omega MIN)(\dot{\Omega} MAX)}{550} \qquad (12)$$

where HPENG = power available at ΩMIN from the engine

ΩMIN = specified minimum rpm

$\dot{\Omega}$MAX = specified maximum bleed rate

MCEP INPUT

HC =50	BINERT=2860	OMGBD1=2	OMGBL4=0	OMGRC3=0
MUF = 0.8	HPMAXT=1200	OMGBL2=0	OMGBD4=0	OMGRD3=0
NMIN = 0.8	EGF = 1	OMGBD2=0	OMGRD1=0	OMGRC4=0
PSU = 1	OMEGMN= 300	OMGBL3=0	OMGRC2=0	OMGRD4=0
MPRINT= 1	NMAXOV= 1.1	OMGBD3=0	OMGRD2=0	

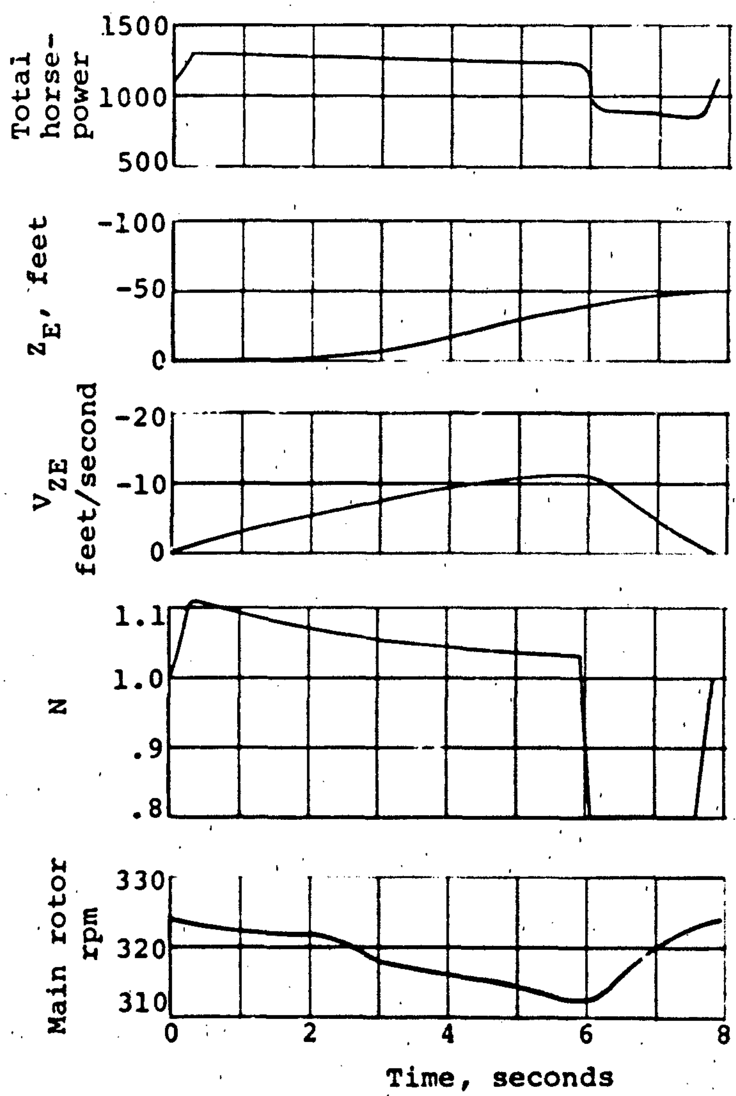

Figure 2. Time history of collective pop-up using bleed rpm maneuver for AH-1G helicopter at hover and 9500 pounds.

If the commanded bank angle is greater than the power limited bank angle, the bank angle is reset to the power limited bank angle. When the power required exceeds the power available from the engine, the rpm bleed phase is initiated. The bank angle is increased to the value estimated from the HPA of Equation (12), and the time to reach the new bank angle is the input value of time to peak bleed rate (TBLED). The actual rpm bleed rate is a function of the power required to increase the bank angle beyond the engine power limited bank angle instead of the input value for the maximum bleed rate allowed (OMGDMX). However, the maximum bleed rate allowed influences the magnitude of the increased bank angle over the power-limited bank angle, as shown in Equation (12). The rpm bleed rate is computed from the difference between power available and power required as follows

$$\dot{\Omega} = \frac{550\ (HPENG - HP)}{(KR)(IR)\Omega} \tag{13}$$

where

HP = power required for the maneuver

Thus, the power deficiency is corrected with stored power from the rotor. The controller estimates the time to reach minimum rpm. Prior to reaching minimum rpm, the controller reduces the bank angle in the above time to the value that can be sustained by engine power at the reduced rpm. The aircraft continues at the steady bank angle until it is time to roll out to arrive at the commanded velocity. This part of the controller is unchanged from the constant rpm maneuver. The capability to spend a specified time TCRUSE at the command velocity prior to turning into the wind has been added.

The input requirements for this maneuver are the command bank angle, command sideward velocity, maneuver urgency factor, tail rotor power, target location X axis, target location Y axis, time to reach peak beta dot, desired beta dot, time to cruise at command velocity, multiple of time increment, blade inertia, main rotor transmission rating, energy efficiency factor, minimum rotor rpm requested, time to bleed, and maximum bleed rate allowed. An example of this maneuver is shown in Figure 3.

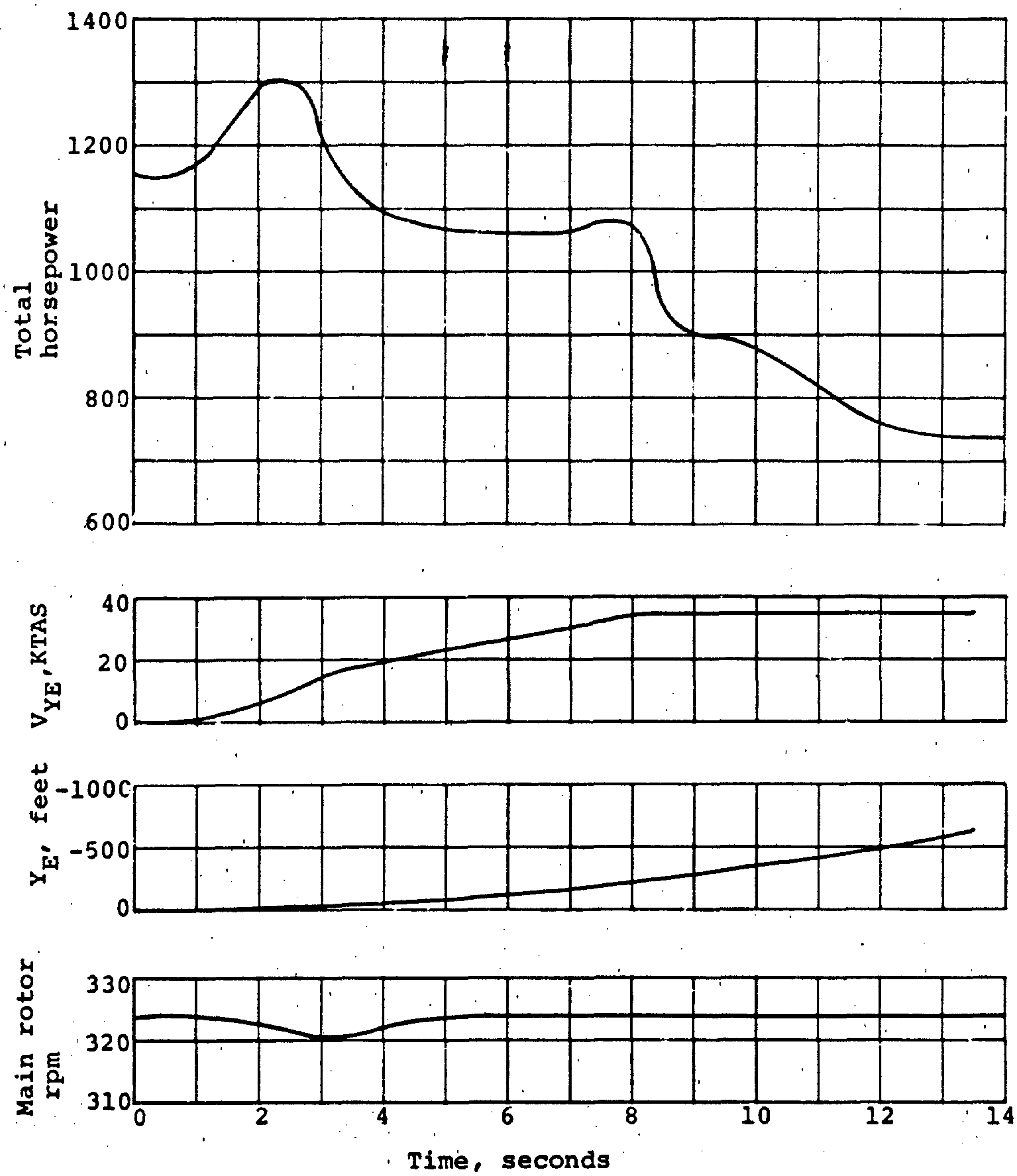

Figure 3. Time history of sideward acceleration from hover and turn into wind using bleed rpm for AH-1G helicopter at 8500 pounds.

MCEP INPUT

PHIC =25	TARX =10000	TCRUSE= 0	EEF = 1
VCRAB=35	TARY = 0	MPRINT= 1	OMEGMN=300
MUF = 1	TPY = 0	BINERT=2860	TBLED = 5
HPMTR= 0	BETAD= 20	HPMAXT=1200	OMGDMX= 4

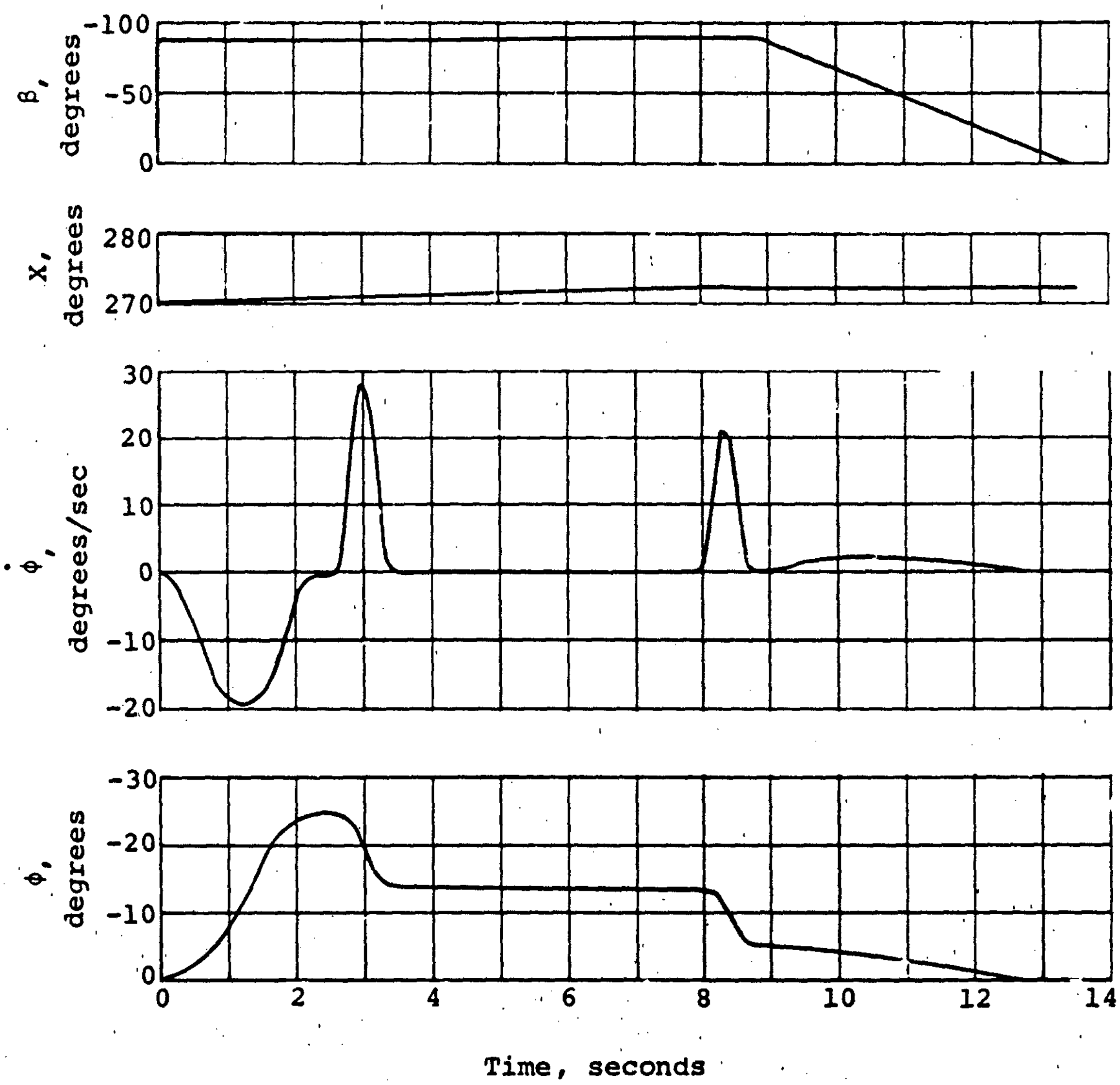

Figure 3. (Concluded.)

TERRAIN AVOIDANCE MANEUVER (PULLUP/PUSHOVER)

The terrain avoidance maneuver provides the capability to determine the response of the helicopter to a specified load factor trace and power available input. The load factor trace and power available input are time variant. The maneuver is flown by specifying up to 21 sets of load factors, time points, and horsepower availables. If the engine horsepower is specified as zero (HPAI=0), the controller computes the engine horsepower as the horsepower required for the maneuver and is limited by HPMAX AND HPMIN. If the value of the first time point TI(1) is not equal to zero, then the controller will interpolate linearly between t=0 and N-1 to t-TI(1) and NI(1). Between specified time points, the load factor N and the horsepower available HPA (if specified) are interpolated linearly. The controller terminates the maneuver when TI(I+1)<TI(I). A corresponding load factor point NI(I) must be specified for each TI(I).

This maneuver has the following restrictions. First, the acceleration is computed using Equation (80), Reference 2, which should not be used below 30 knots during any part of the maneuver. The second limitation is that this maneuver must be entered and exited at a load factor of 1.

An example of this maneuver is presented in Figure 4. The input requirements for this maneuver are the time points for specified load factors and horsepower supplied, the load factors corresponding to the specified time points and horsepower supplied from the engine, minimum power setting, and multiple of time increment for time history output.

SPEED POWER POLAR

This maneuver provides the capability to compute speed power polars for the specified helicopter. These can be compared to measured speed power polars to determine the extent of agreement. The impact of varying the inputs in the rotor group can be evaluated. This maneuver also allows for the sweeping of gross weight and load factor. The computer will plot the total power as well as the different power components. The velocity and horsepower plot ranges will apply to all speed power polars generated in the sweep. If the velocity and/or horsepower plot ranges are zero, the plot range will be computed for each speed power polar in the sweep.

MCEP INPUT

```
TI = 0.0      3.000  4.000  5.000  9.000  9.300  13.500 14.000 17.000 17.500 18.250
     18.300  19.500 20.000 22.000 22.500 23.750 24.500
NI = 1.0000  1.0000 2.0000 1.0000 1.0000 0.5000 0.6000 0.0    0.0    0.0
     1.4000  1.4000 1.0000 1.0000 0.6000 0.6000 1.0000 1.0000 1.0000 2.0000 2.0000
HPAI =  0.0     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
PSL = 0.5000 MPRINT = 1  0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

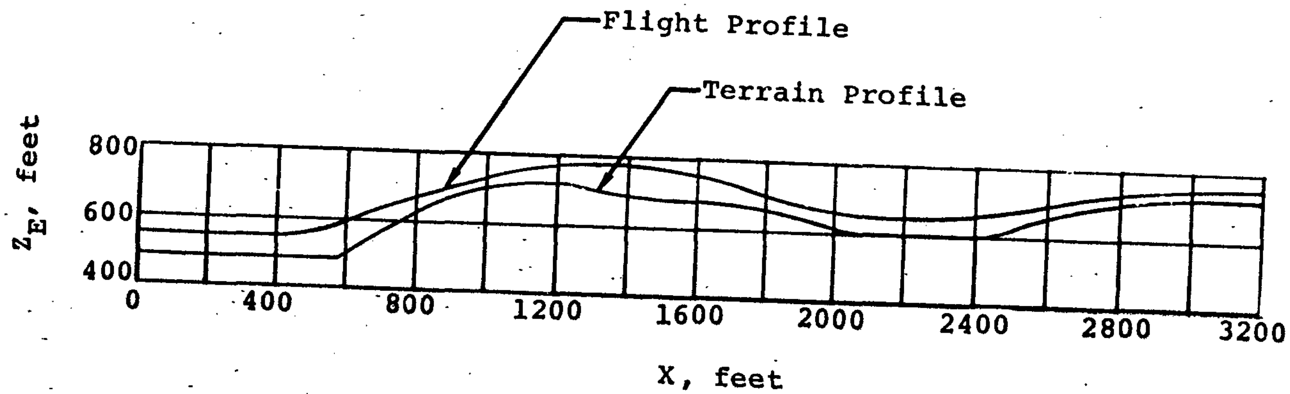

Figure 4. Time history of terrain avoidance maneuver for the AH-1G helicopter entered at 60 knots and 7000 pounds.

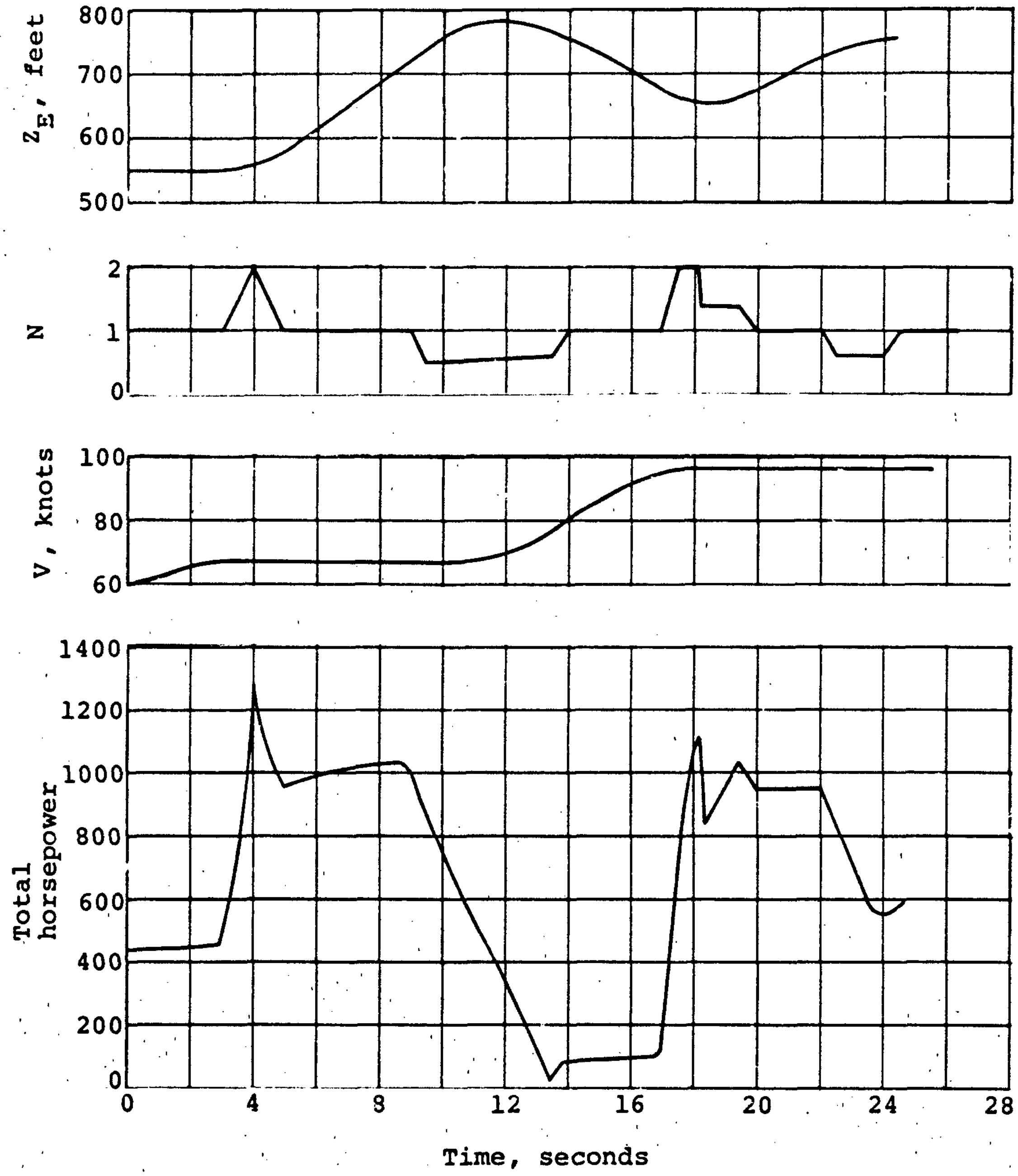

Figure 4. (Concluded.)

An example of this maneuver is presented in Table 1. These data are for the AH-1G helicopter at 9500 pounds. The input requirements are minimum and maximum velocity on plot, minimum and maximum horsepower on plot, plot symbols for each of the power components, initial and final speed for speed power polar, speed increment, initial and final load factor and load factor increment, initial and final gross weight, and gross weight increment for sweep.

TABLE 1. POWER REQUIRED VERSUS AIRSPEED FOR AH-1G HELICOPTER AT 9500 POUNDS

```
0 PLOT RANGES:   VEL MIN =    0.0     VEL MAX = 140.0      HP MIN =     0.     HP MAX =   400.
  PLOT SYMBOLS:  HPTOTAL =T   HP1 =1  HP2 =2  HP3 =3  HP4 =4  HP5 =5  HP6 =6  HP7 =7  HPS =S

  INPUT DATA:          VU =     0.0   VFN =  140.0    DELV =   5.00    NU =   1.000    NFN =   1.000    DELN = 1.000
                      GWU =  9500.0   GWFN =       1.0   DELGW = 9500.0
1                  LOAD FACTOR =   1.000              GROSS WEIGHT =   9500.0
```

V KT	HPTOTAL HP	HP1 HP	HP2 HP	HP3 HP	HP4 HP	HP5 HP	HP6 HP	HP7 HP	HPS HP
0.0	1155.1	0.0	843.4	166.6	145.1	0.0	0.0	0.0	0.0
5.0	1127.6	0.0	815.7	166.7	145.2	0.0	0.0	0.0	0.0
10.0	1078.6	0.2	756.0	167.0	145.4	0.0	0.0	0.0	0.0
15.0	1013.2	0.7	699.1	167.5	145.9	0.0	0.0	0.0	0.0
20.0	938.8	1.6	622.5	168.2	146.5	0.0	0.0	0.0	0.0
25.0	864.3	3.2	544.8	169.1	147.2	0.0	0.0	0.0	0.0
30.0	796.9	5.5	473.1	170.1	148.2	0.0	0.0	0.0	0.0
35.0	740.4	8.7	411.0	171.4	149.3	0.0	0.0	0.0	0.0
40.0	695.4	13.0	358.9	172.9	150.6	0.0	0.0	0.0	0.0
45.0	660.7	18.5	315.6	174.5	152.1	0.0	0.0	0.0	0.0
50.0	635.1	25.3	279.6	176.4	153.7	0.0	0.0	0.0	0.0
55.0	625.2	33.7	249.5	178.5	155.5	8.0	0.0	0.0	0.0
60.0	615.9	43.8	224.0	180.7	157.5	9.8	0.0	0.0	0.0
65.0	615.9	55.7	205.3	183.2	159.7	12.1	0.0	0.0	0.0
70.0	623.0	69.5	190.9	185.8	162.0	14.[illegible]	0.0	0.0	0.0
75.0	635.0	85.5	178.4	188.7	164.6	17.8	0.0	0.0	0.0
80.0	651.7	103.8	167.4	191.7	167.3	21.5	0.0	0.0	0.0
85.0	673.2	124.5	157.7	194.9	170.2	25.9	0.0	0.0	0.0
90.0	699.6	147.8	149.0	198.4	173.3	31.0	0.0	0.0	0.0
95.0	730.8	173.8	141.3	202.0	176.6	37.1	0.0	0.0	0.0
100.0	767.2	202.8	134.3	205.8	180.1	44.2	0.0	0.0	0.0
105.0	808.9	234.7	128.0	209.9	183.9	52.5	0.0	0.0	0.0
110.0	850.2	269.9	122.3	214.1	187.8	62.2	0.0	0.0	0.0
115.0	909.3	308.4	117.1	218.5	191.9	73.4	0.0	0.0	0.0
120.0	968.5	350.4	112.3	223.1	196.3	86.5	0.0	0.0	0.0
125.0	1034.3	396.0	107.9	227.9	200.8	101.6	0.0	0.0	0.0
130.0	1106.9	445.5	103.9	232.9	205.7	119.0	0.0	0.0	0.0
135.0	1186.8	496.9	100.2	238.1	210.7	138.9	0.0	0.0	0.0
140.0	1274.4	556.4	96.8	243.5	216.0	161.8	0.0	0.0	0.0

COMPARISON OF MCEP BLEED RPM MANEUVERS WITH MEASURED MANEUVERS

The three new bleed rpm maneuvers added to MCEP have been compared with both constant and bleed rpm maneuvers flown during the flight evaluation of a high energy rotor system on an OH-58A helicopter, as reported in Reference 3. The rotor system evaluated was not a standard OH-58A rotor system. The blades were modified with external doublers, a trailing edge tab, and a different hub configuration, as described in Reference 3.

The MCEP maneuvers were evaluated by inputting the atmospheric conditions, gross weight, rpm bleed rate, and engine power produced during the measured maneuvers. The resulting main rotor rpm variation with time, the flight profile, and the velocity were compared to the measured data to validate the mathematical model. The validity of each of the new MCEP maneuvers is confirmed from the comparison with measured data.

POWER CORRELATION

The new maneuver for computing speed power polars from the helicopter aerodynamic data was used to match the computed power required versus the measured power required. The power required for this Model OH-58A with the high energy rotor system is different from that for the standard Model OH-58A. The blades have an upper- and lower-surface external doubler near the leading edge, and the chord was extended by 3 inches using a trailing-edge tab (chord increased from 13 inches to 16 inches). To make a trim tab, the outboard portion of the trailing-edge tab was cut and bent up. The hub configuration was different and chinese weights were added to the hub, raising the hub drag. The rotor inputs were modified from the standard Model OH-58A rotor inputs to reflect the dirty aerodynamic configuration of the blades. The flat plate drag of the aircraft was increased to account for the hub drag increase.

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[3] Dooley, L. W. and Yeary, R. D., Bell Helicopter Textron; FLIGHT TEST EVALUATION OF THE HIGH INERTIA ROTOR SYSTEM, USARTL Technical Report 79-9, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia

No performance flights were actually flown in the high energy rotor system configuration. The power required was based on engine torque readings from the load level flights, and the hover data was based on stabilized points prior to the throttle chop. Figure 5 presents the estimated power required based on the above considerations and the measured power. The computed MCEP power matches the measured data. Table 2 gives the input data for the OH-58A in the high energy rotor system configuration used for this validation work.

COMPARISON BETWEEN MEASURED AND PREDICTED ACCELERATION MANEUVERS USING CONSTANT AND BLEED RPM

The acceleration at constant altitude maneuvers was used to predict the acceleration maneuver measured on Flight 180A, counter number 928. This maneuver was flown by the Army evaluation pilot. A comparison of the predicted and measured data is presented in Figure 6. The predicted distance versus time matches the measured data within 20 feet out of 1700 feet. The velocity versus time generally agrees with the measured data within 2 knots. The measured velocity data comes from taking the time derivative of the horizontal distance. The two symbols on the horsepower plot are for the engine horsepower produced and for the total horsepower used for the maneuver. The total horsepower is calculated from the measured rate of change of rotor rpm according to Equation (6), and added to the engine horsepower.

The acceleration at constant altitude using the bleed rpm maneuver was used to predict the acceleration maneuver measured on Flight 180A, counter number 929. The results of this comparison are presented in Figure 7. MCEP has no provision for varying the altitude during this maneuver. The measured maneuver had an altitude gain of 22 feet during the maneuver. Also, only the MCEP has the capability to bring power in linearly, while the measured data show the power application to be more of an exponential nature. The comparison presented in Figure 7 represents the best overall match of main rotor rpm, horizontal distance, power applied, rate of change of main rotor rpm, and horizontal velocity. In the computed maneuver, the power is applied quicker than the measured data. The computed main rotor rpm agrees with the measured main rotor rpm, and the rate of change of main rotor rpm was modeled as shown in Figure 7. The computed horizontal distance is 21 feet on the low side of the measured data (out of 1280 feet) in 14 seconds. The computed horizontal velocity is within 2 knots of the measured velocity at the end of 14 seconds.

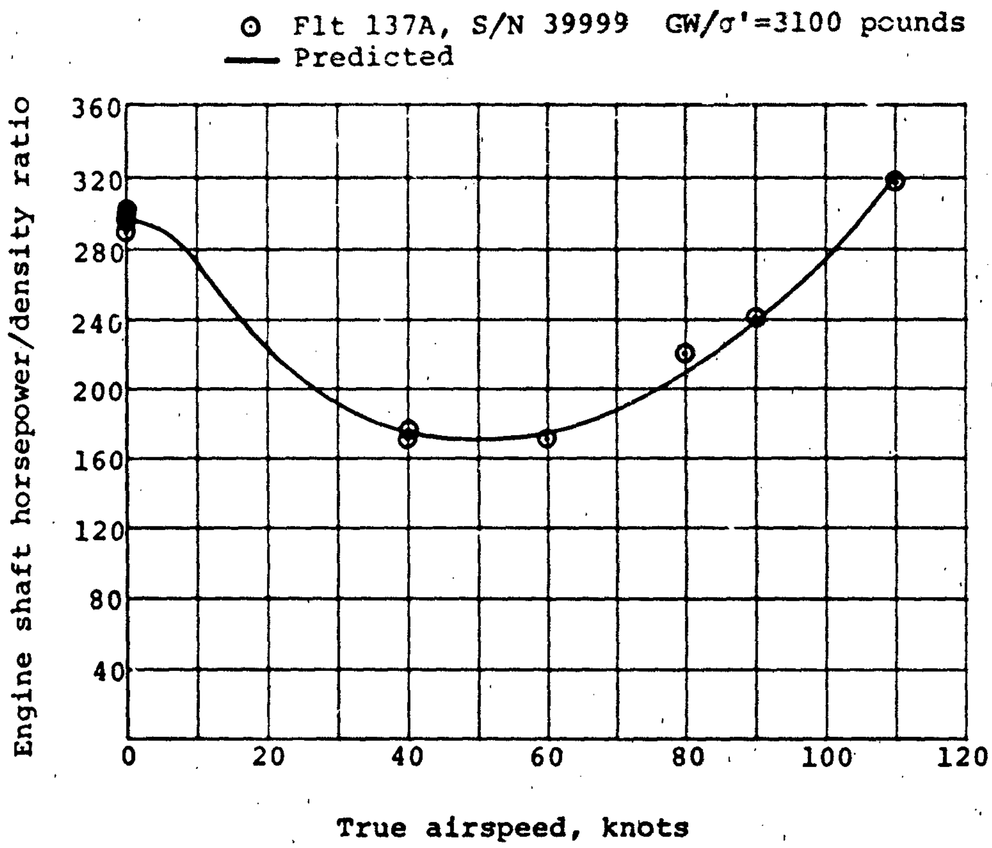

Figure 5. Measured and predicted power required versus airspeed for the OH-58A helicopter with the high energy rotor installed.

TABLE 2. INPUT DATA FOR OH-58A HELICOPTER WITH HIGH ENERGY ROTOR SYSTEM INSTALLED

MANEUVER CRITERIA EVALUATION PROGRAM

HERSM20 05/13/79 HIGH ENERGY ROTOR SYSTEM SIMULATION

HELICOPTER INPUT DATA

VARIABLE	DIGITAL NAME	VALUE	UNITS
ROTOR			
NUMBER OF BLADES	B	2.000	N.D.
ROTOR CHORD	C	1.330	FT
ROTOR RADIUS	R	17.650	FT
MAIN ROTOR INDUCED VELOCITY FACTOR	K3	2.140	N.D.
TIP SPEED	WR	654.000	FT/SEC
BLADE SECTION LIFT CURVE SLOPE	A2D	6.280	/RAD
BLADE DRAG COEFFICIENTS:	DEL0	0.0110	N.D.
	DEL1	0.0	/RAD
	DEL2	0.590	/RAD*RAD
DRAG DIVERGENT MACH NUMBER	MCRO	0.750	N.D.
DIVERGENT THRUST COEFFICIENTS CURVE:	TC1	0.100	N.D.
	TC2	0.200	N.D.
MAXIMUM THRUST COEFFICIENTS CURVE:	TCM1	0.360	N.D.
	TCM2	0.0	N.D.
GROUND EFFECT CONSTANTS:	GEFFZA	0.993	N.D.
	GEFFZB	0.038	N.D.
HEIGHT FROM SKID TO PITCH CHANGE AXIS	SKTPCA	0.0	FT
CLIMB/DESCENT EFFICIENCY FACTOR	HPEFF	0.800	N.D.
FUSELAGE			
EQUIVALENT FLAT PLATE DRAG(BETA=0)	F0	11.700	FT**2
EQUIVALENT FLAT PLATE DRAG(BETA=90)	F1	100.000	FT**2
FUSELAGE ANGLE OF ATTACK COEFFICIENTS:	KAF1	8.643	
	KAF2	2.478	1/G*G
	KAF3	10.422	1/G
	KAF4	1.600	
	KAF5	16.980	SEC/FT
	KAF6	0.800	N.D.
	KAF7	-3.800	DEG
	KAF8	240.000	N.D.
WILL WING BE REPRESENTED	WING	F	

TABLE 2. CONCLUDED.

VARIABLE	DIGITAL NAME	VALUE	UNITS
WING			
WING AREA	SW	0.0	FT**2
WING INCIDENCE	IW	0.0	DEG
INDUCED VELOCITY FACTOR	KW	0.0	N.D.
WING ASPECT RATIO	ASR	0.0	N.D.
WING COEFFICIENT OF DRAG AT ZERO LIFT	CD0	0.0	N.D.
WING LIFT CURVE SLOPE	AL2D	0.0	/RAD
FLAT PLATE DRAG COEFFICIENT	CDFP	0.0	N.D.
WING EFFICIENCY FACTOR	WEFF	0.0	N.D.
WING INCIDENCE CHANGE WITH LOAD FACTOR	DIWDN	0.0	DEG/G
MAXIMUM POSITIVE LIFT COEFFICIENT	CLMAXP	0.0	N.D.
MAXIMUM NEGATIVE LIFT COEFFICIENT	CLMAXN	0.0	N.D.
PRINT WING OUTPUT DATA	WINGPRT	F	
PERFORMANCE LIMITS			
LIMIT DIVE VELOCITY	VDL	140.000	KT
MAXIMUM VELOCITY TO THE RIGHT	VMRT	55.000	KT
MAXIMUM VELOCITY TO THE LEFT	VMLT	-55.000	KT
MAXIMUM TIME TO APPLY POWER	TMAX	4.000	SEC
MINIMUM TIME TO APPLY POWER	TMIN	1.000	SEC
TIME CONSTANT FOR GAMMA	TAUP	1.000	SEC
TIME CONSTANT FOR ROLL	TAUR	0.500	SEC
TIME CONSTANT FOR CHI	TAUY	0.500	SEC
MAXIMUM RATE FOR GAMMA	ARPMX	30.000	DEG/SEC
MAXIMUM RATE FOR ROLL	ARRMX	60.000	DEG/SEC
MAXIMUM RATE FOR CHI	ARYMX	60.000	DEG/SEC
MAXIMUM ANGLE FOR GAMMA	GAMMP	60.000	DEG
MINIMUM ANGLE FOR GAMMA	GAMMN	-60.000	DEG
VERTICAL JERK LIMIT	VJERK	0.500	G/SEC

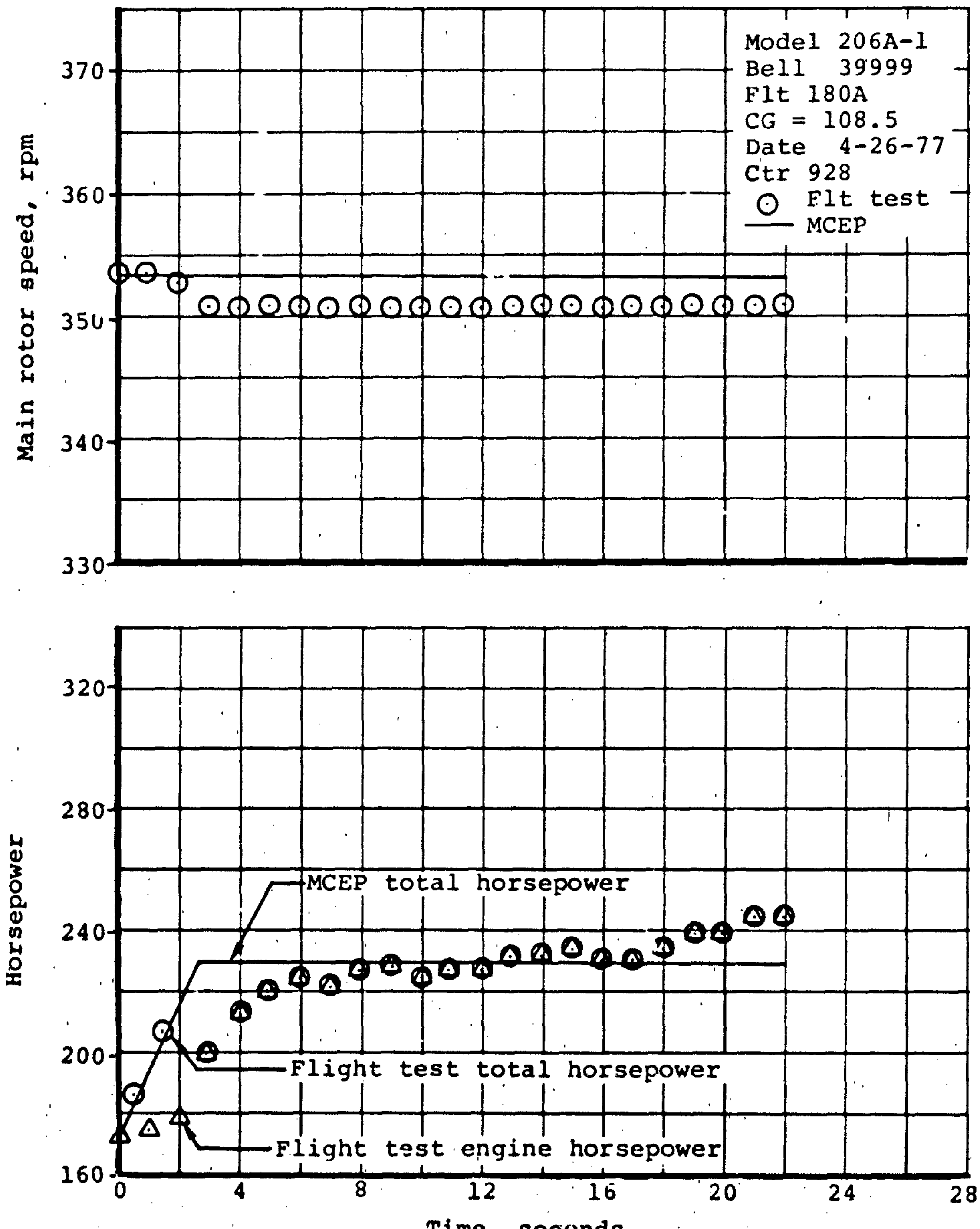

Figure 6. Time history of longitudinal acceleration without bleed of rpm (Maneuver No. 2).

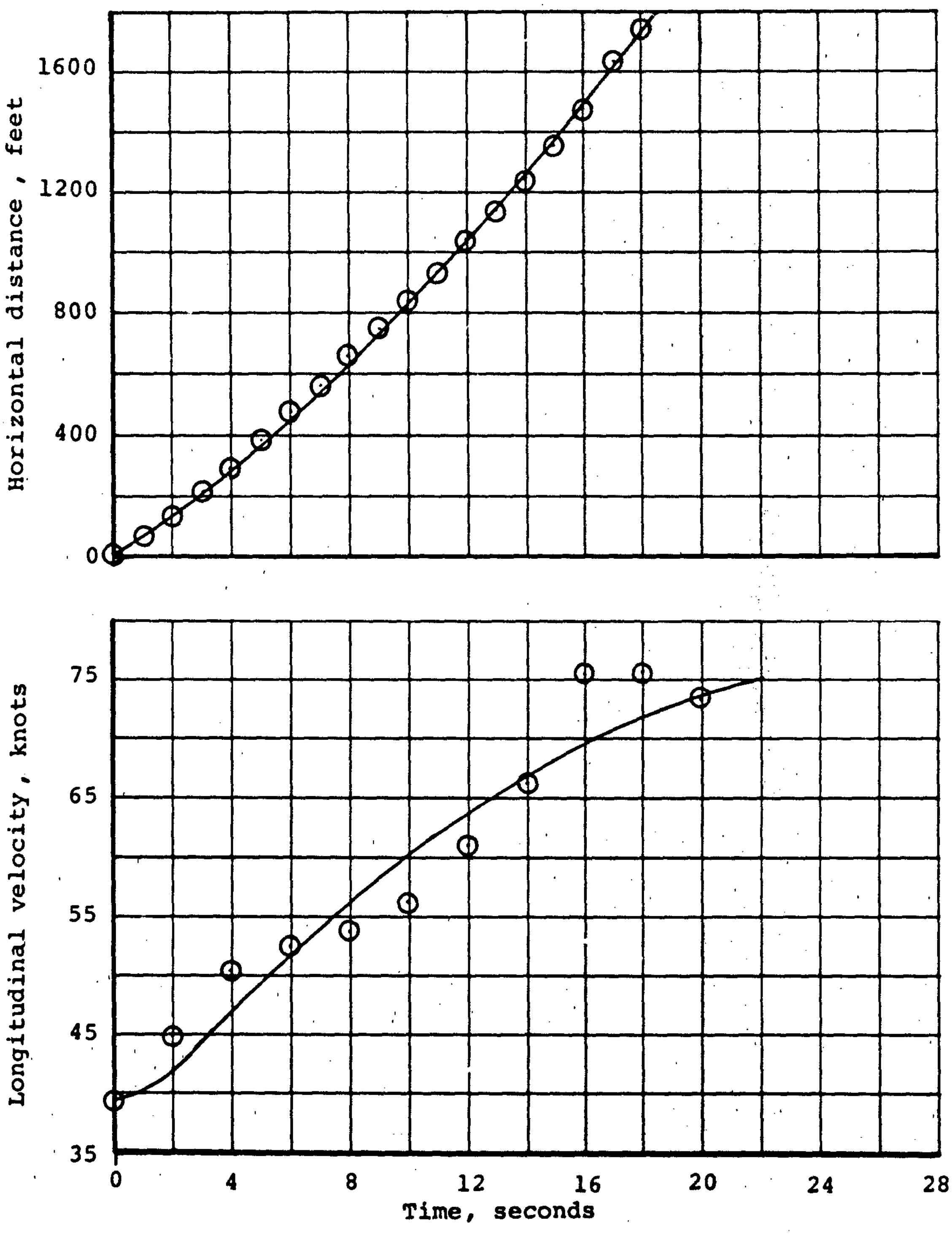

Figure 6. (Concluded.)

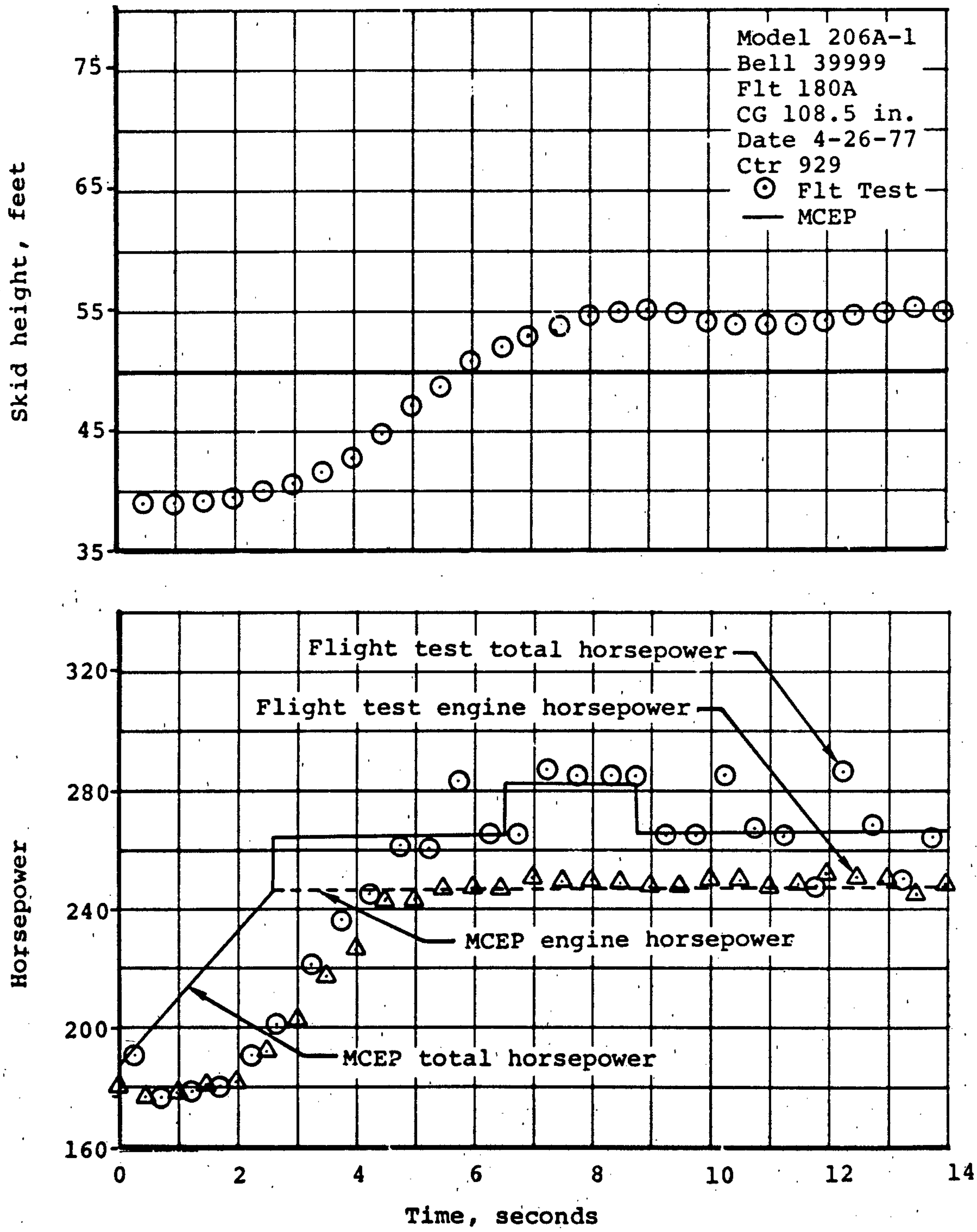

Figure 7. Time history of longitudinal acceleration with bleed of rpm (Maneuver No. 16).

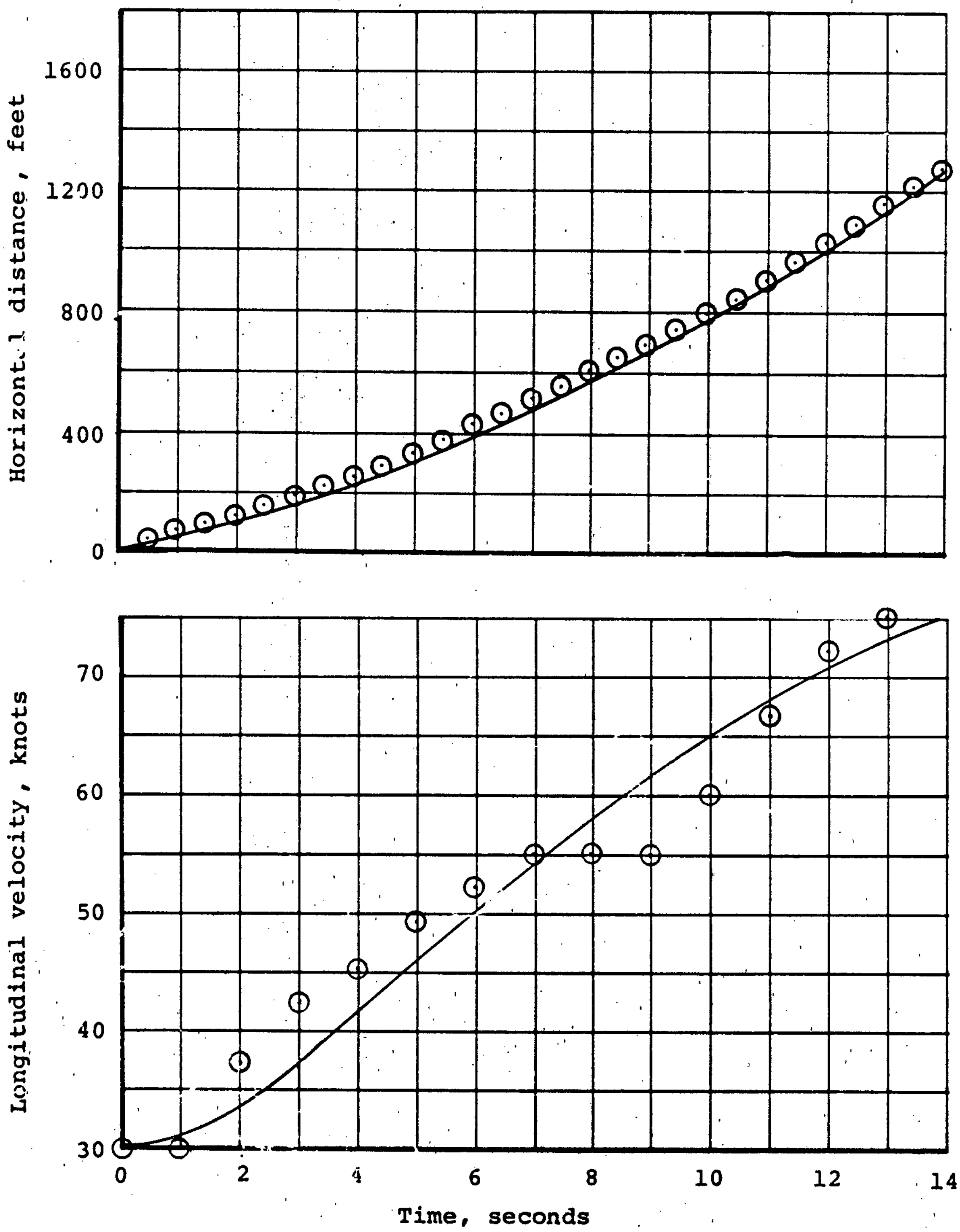

Figure 7. (Continued.)

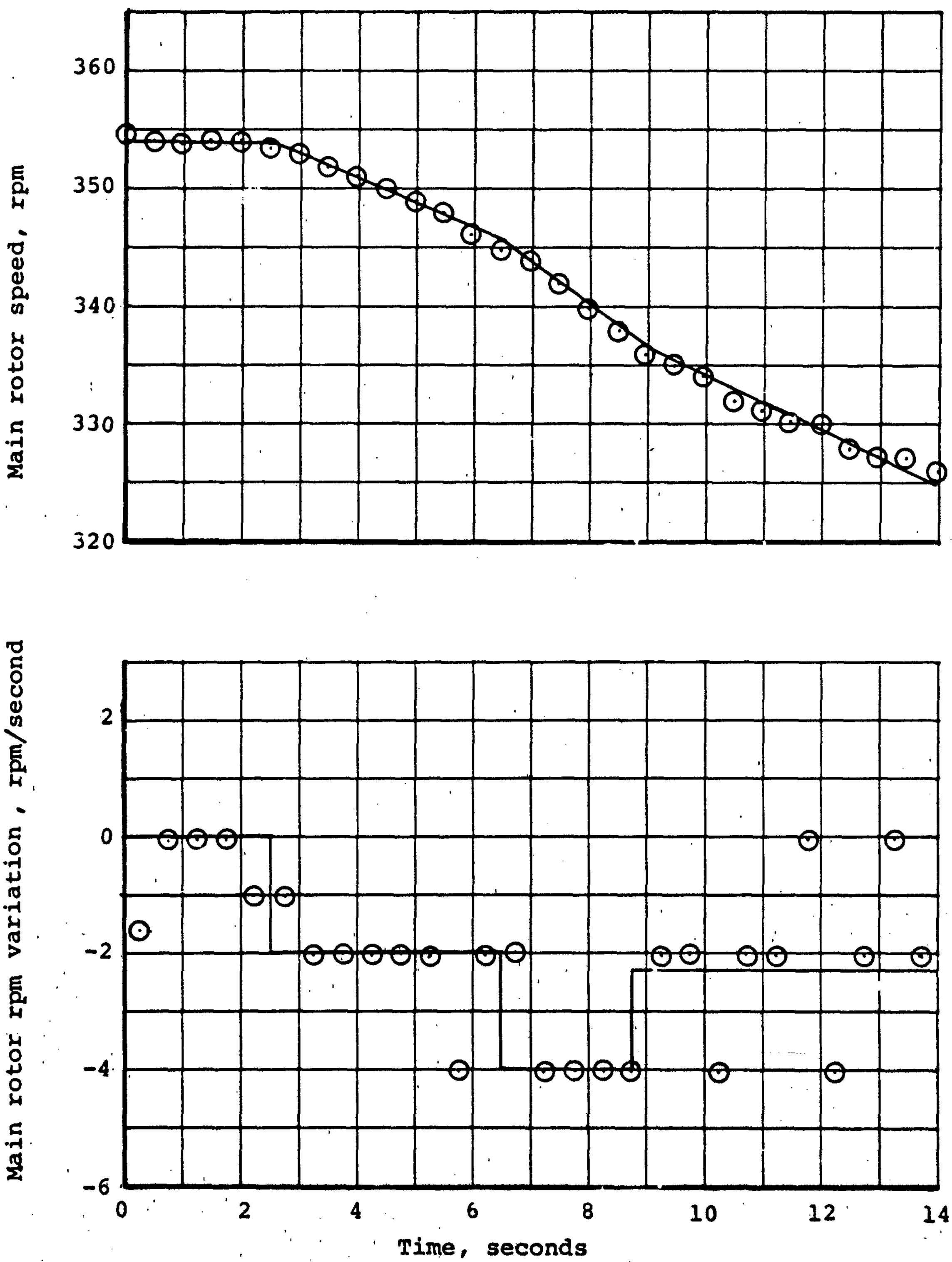

Figure 7. (Concluded.)

The MCEP representation of the acceleration at constant altitude using bleed rpm is accurate and on the conservative side when compared to measured data for the maneuver.

COMPARISON BETWEEN MEASURED AND PREDICTED MANEUVER OF COLLECTIVE POP-UP USING CONSTANT AND BLEED RPM

The collective pop-up maneuver was used to predict the collective pop-up maneuver measured on Flight 171, counter number 475. The engine power available was restricted mechanically during the maneuver to simulate a hot-day condition. As a result, the helicopter could not hover out-of-ground effect. A comparison of the predicted and measured data for a collective pop-up maneuver from hover is presented in Figure 8. The computed height agrees with the measured height during the maneuver. A good match between the computed and measured horsepower required was achieved.

The collective pop-up maneuver starting from a hover using bleed rpm was used to predict the collective pop-up maneuver measured on Flight 171, counter number 476. The results of this comparison are presented in Figure 9. The main rotor rpm comparison is within 1 rpm until the recover phase (after 16 seconds) where the deviation is as high as 3 rpm. The computed horsepower is within 3 horsepower for the measured engine power supplied and within 5 horsepower for the total power supplied (engine plus power extracted from the rotor). The computed height is within 2 feet of the measured height. These comparisons show that the MCEP maneuvers are accurate for simulating these types of maneuvers.

COMPARISON BETWEEN MEASURED AND PREDICTED SIDEWARD ACCELERATION MANEUVERS USING CONSTANT AND BLEED RPM

The sideward acceleration maneuver was used to predict the sideward acceleration maneuver measured during Flight 171, counter number 484. This maneuver is one of the more difficult maneuvers to model because of its complex power management. The limitations of the math model to roll a given bank angle and hold it makes exact comparisons with measured data difficult in the roll axis. Since the roll axis controls the maneuver, other parameters such as lateral distance and velocity may vary from the measured data. Comparison of the predicted and measured data for a sideward acceleration maneuver using constant rpm is presented in Figure 10. The predicted roll angle agrees with the measured roll angle in peak magnitude and time to reach that value. However, the predicted

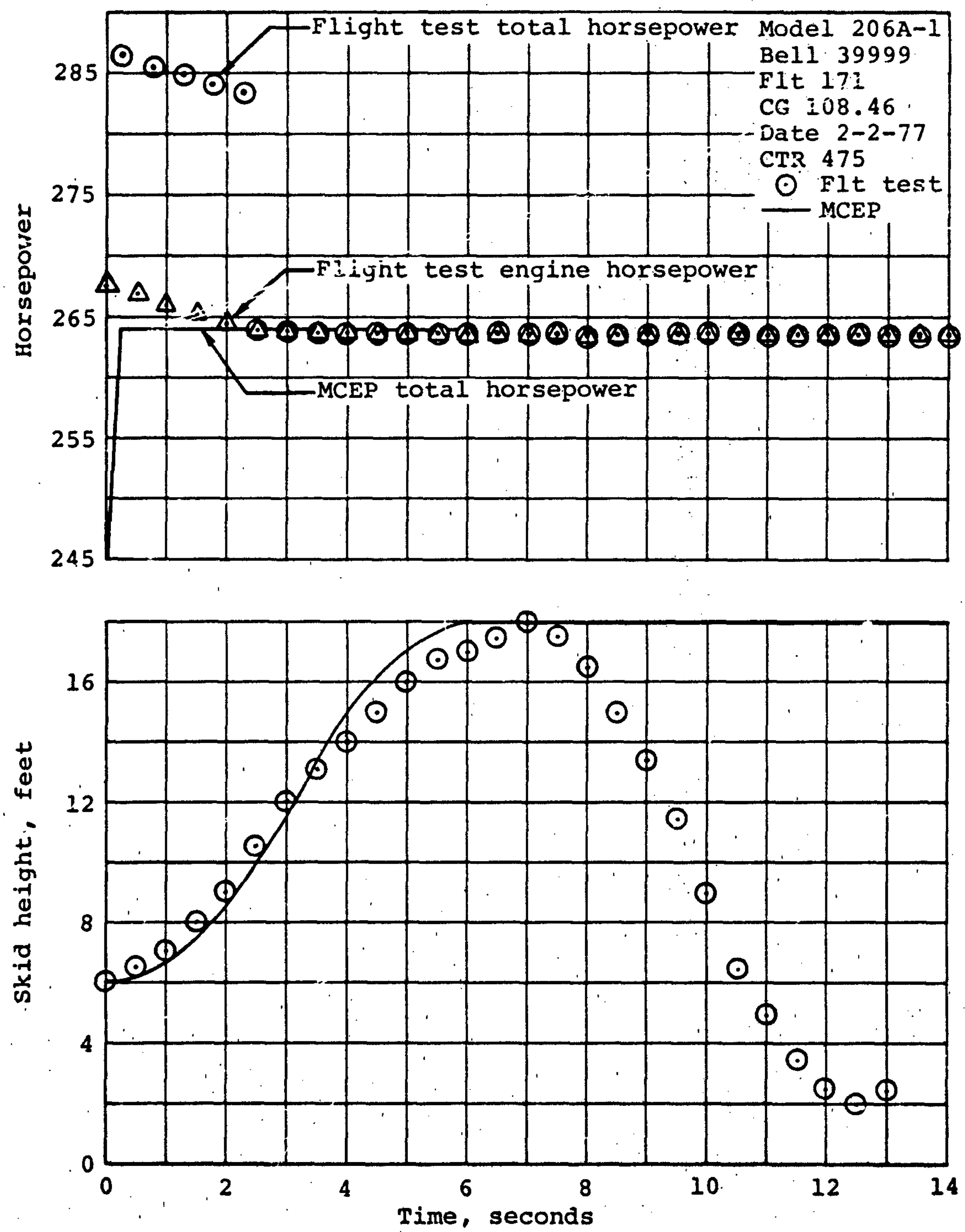

Figure 8. Time history of collective pop-up without bleed of rpm (Maneuver No. 14)

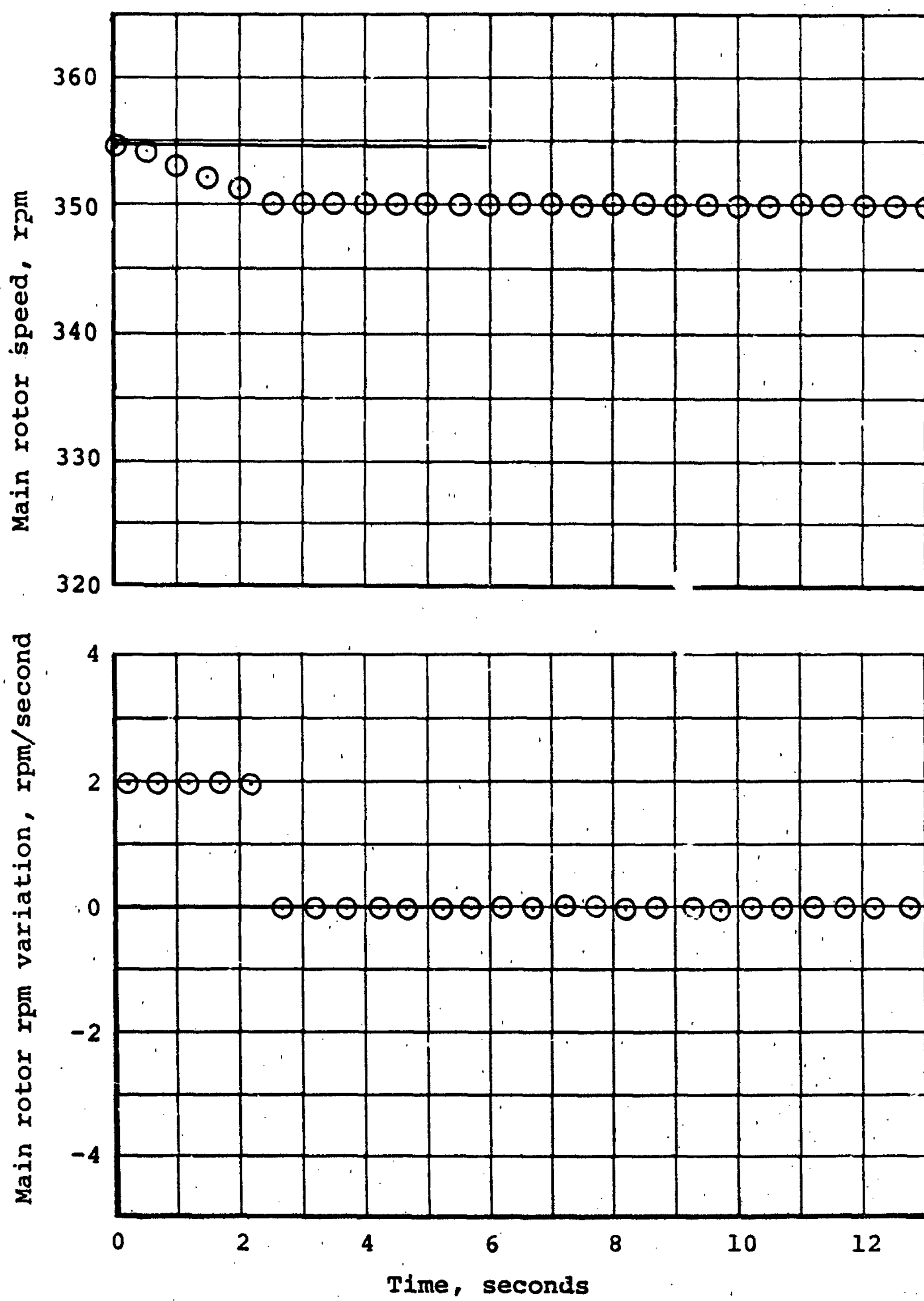

Figure 8. (Concluded.)

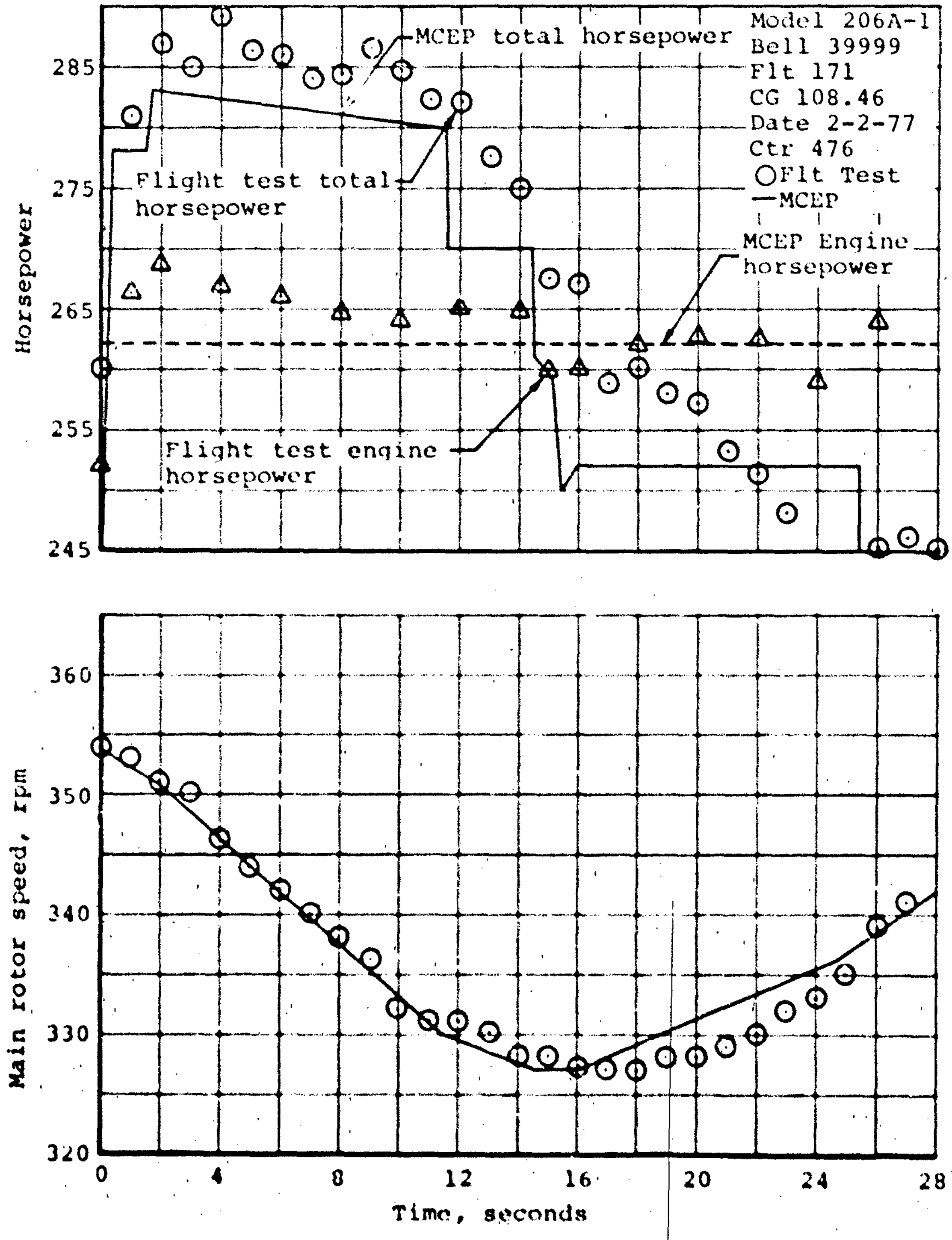

Figure 9. Time history of collective popup with bleed of main rotor rpm (Maneuver No. 17).

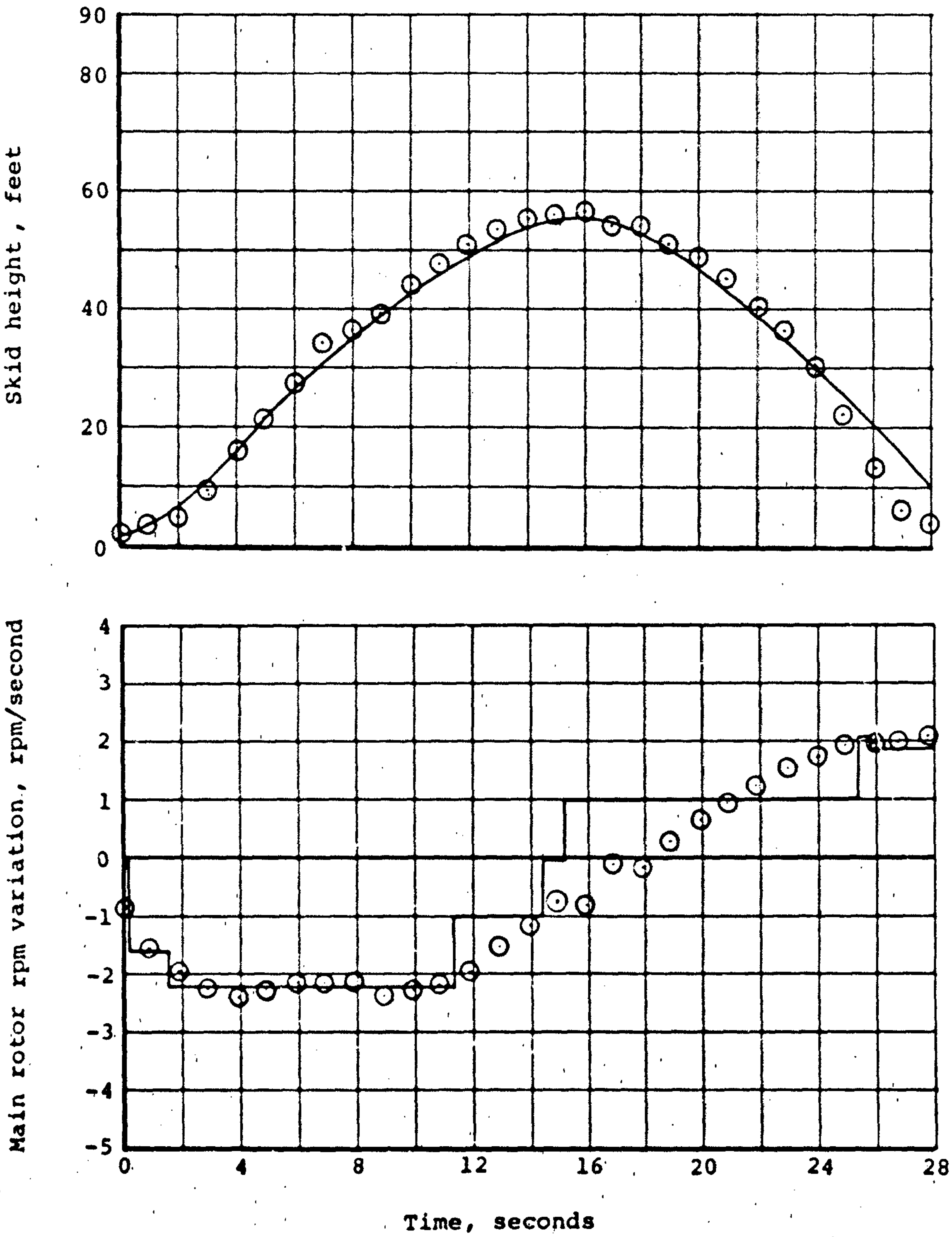

Figure 9. (Concluded.)

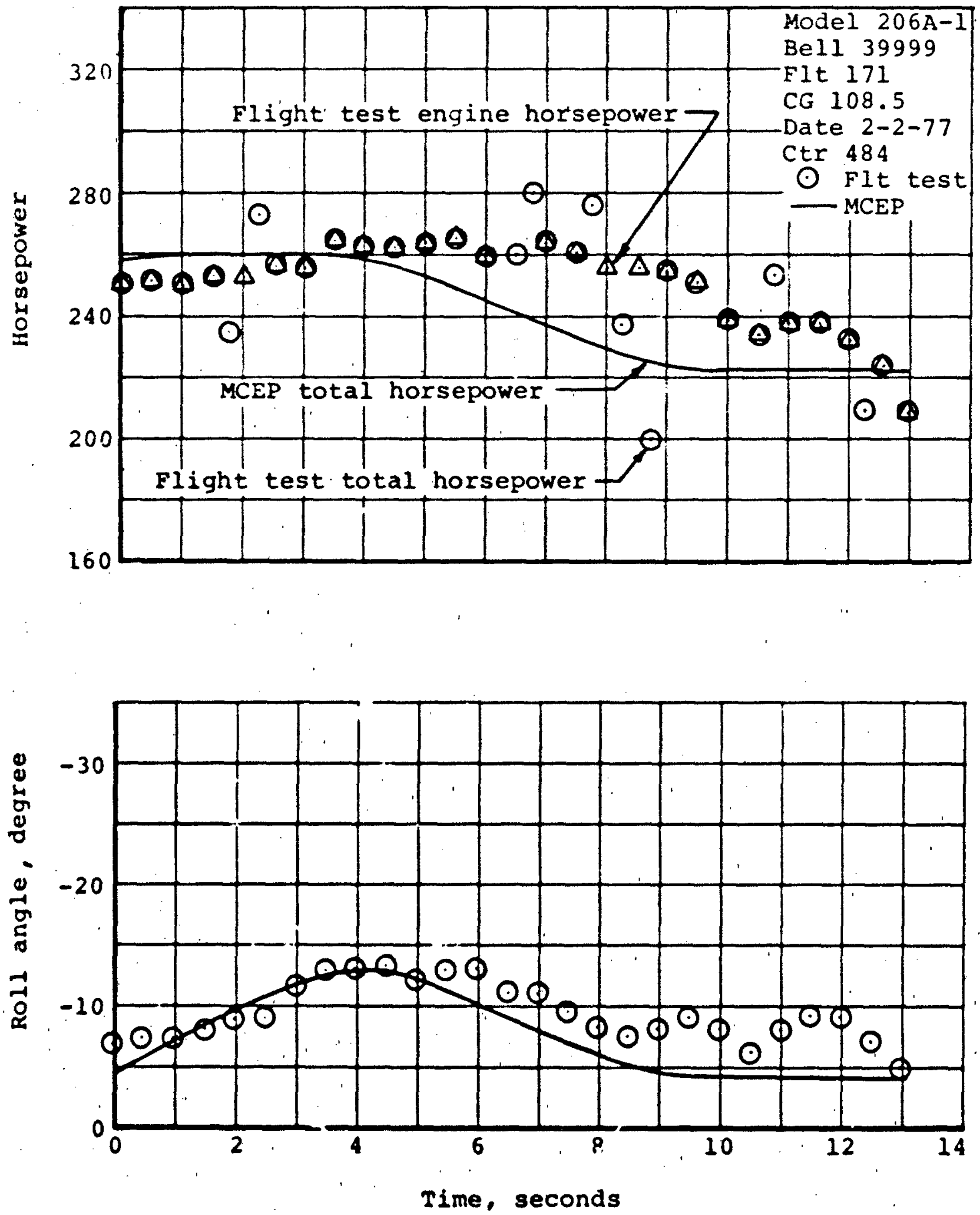

Figure 10. Time history of sideward acceleration without bleed of rpm (Maneuve · No. 11).

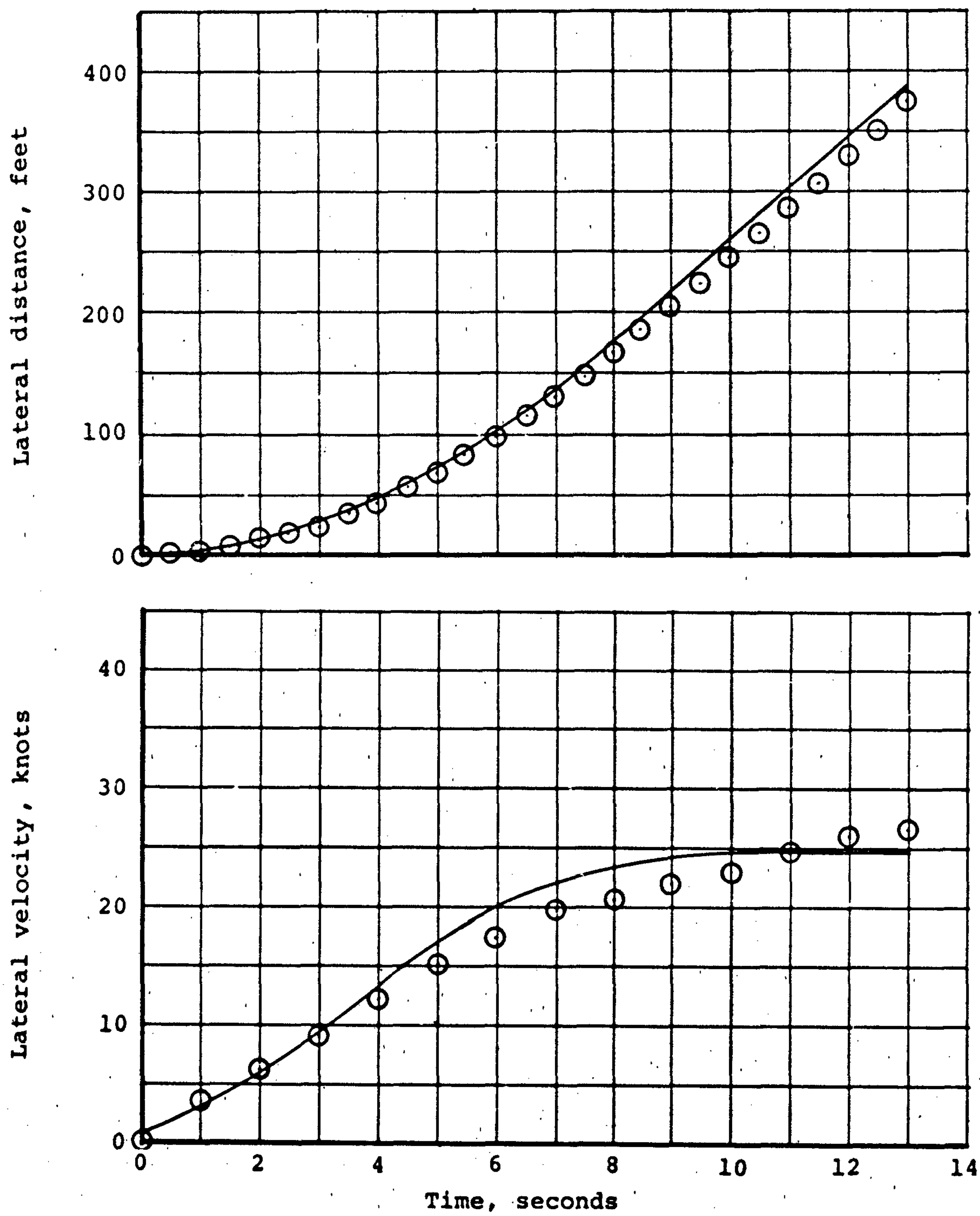

Figure 10. (Continued.)

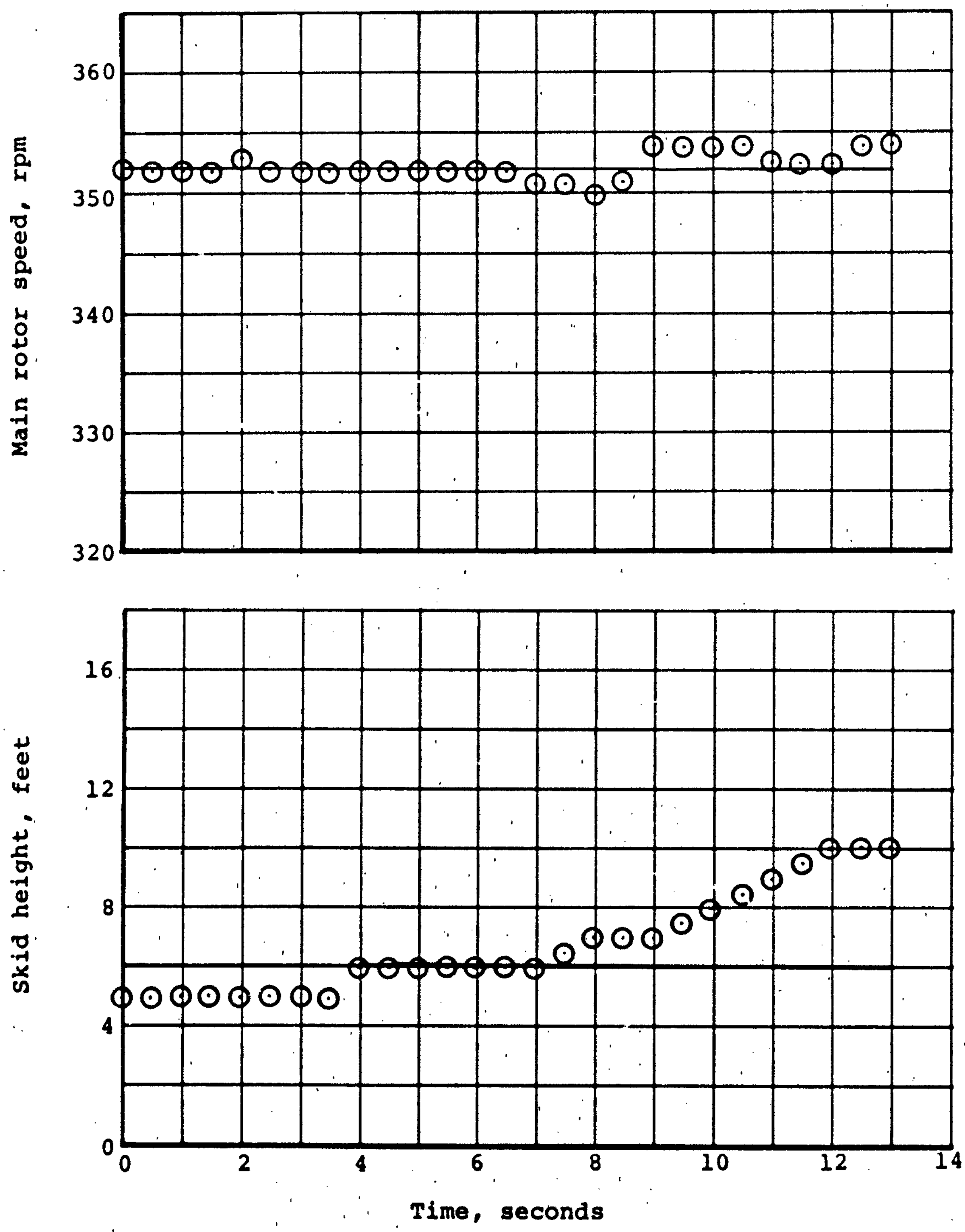

Figure 10. (Concluded.)

roll angle is reduced quicker than the measured roll angle to the final steady state value for trim. As a result of the reduction in predicted roll angle, the predicted power required is reduced from the measured power required in the area of the difference in roll angle. The predicted lateral displacement is usually within 5 to 10 feet of the measured value. The predicted lateral velocity is in agreement with the measured data to within 2 knots.

The sideward acceleration maneuver using bleed rpm was used to predict the sideward acceleration maneuver measured on Flight 171, counter number 485. The comparison between predicted and measured data is presented in Figure 11. The predicted roll angle agrees with the measured roll angle for the first six seconds. After that time, the limitation of the math model precludes matching the measured data. The MCEP maneuver logic does not allow it to continue at an intermediate power limited bank angle once the decision to roll out to the steady state trim angle has been made. Also, the MCEP maneuver logic does not allow a specified bleed rate to be used. Instead, the bleed rate is based on the power demand at the given bank angle to maintain altitude. This logic keeps the predicted main rotor rpm bleed rate and main rotor rpm from agreeing with the measured data. The predicted lateral distance is under by 15 feet (out of 390 feet) and the final sideward velocity is lower by 2 knots. Also, the math model is limited to putting in full engine power before allowing rotor rpm bleed. The measured data show an rpm bleed prior to achievement of full engine power. This results from the engine not being able to accelerate as fast as the power demand, which causes rotor rpm bleed.

The MCEP maneuvers provide a reasonable estimate of sideward acceleration maneuvers in spite of the limitations of the math model and controller.

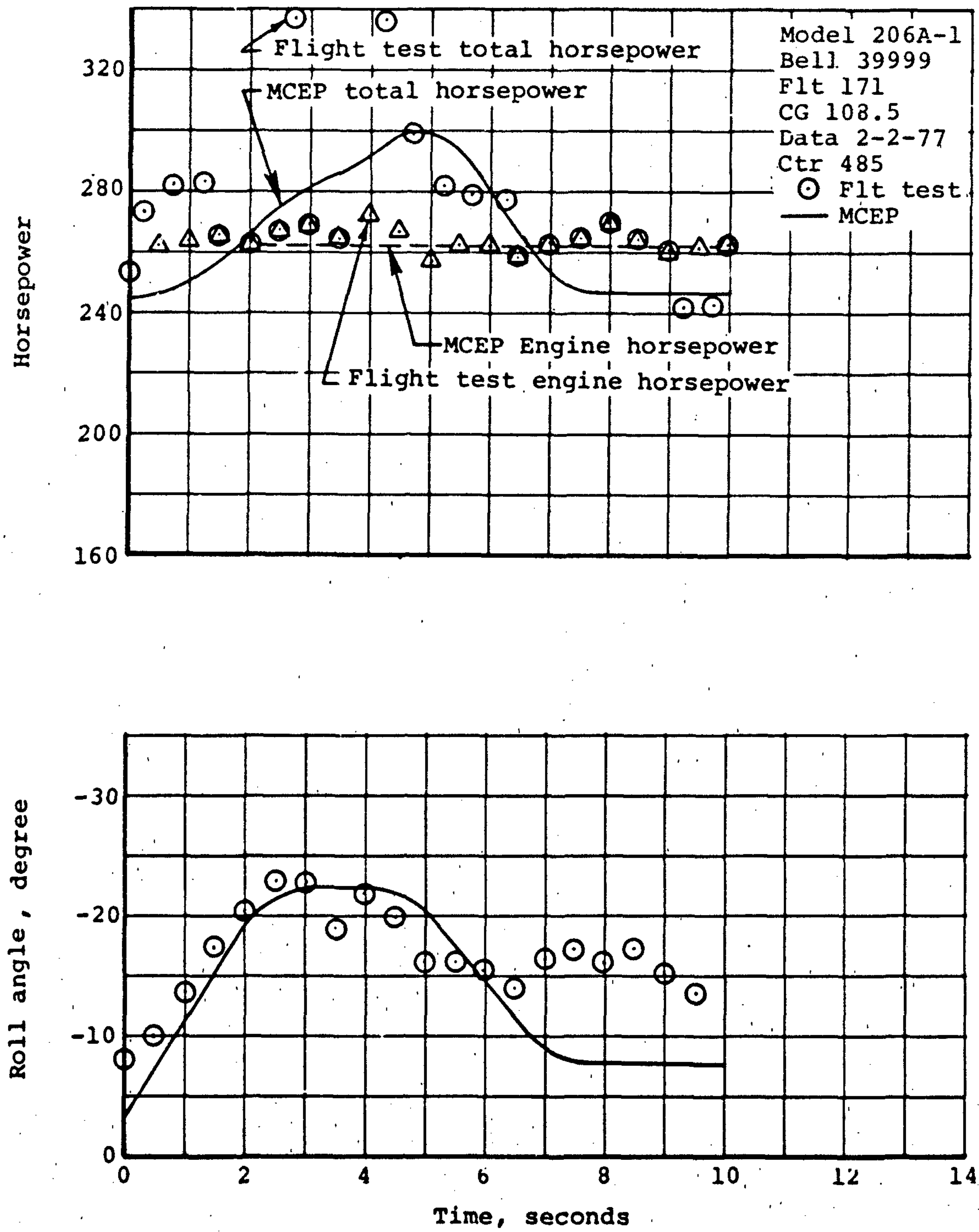

Figure 11. Time history of sideward acceleration with bleed of rpm (Maneuver No. 18).

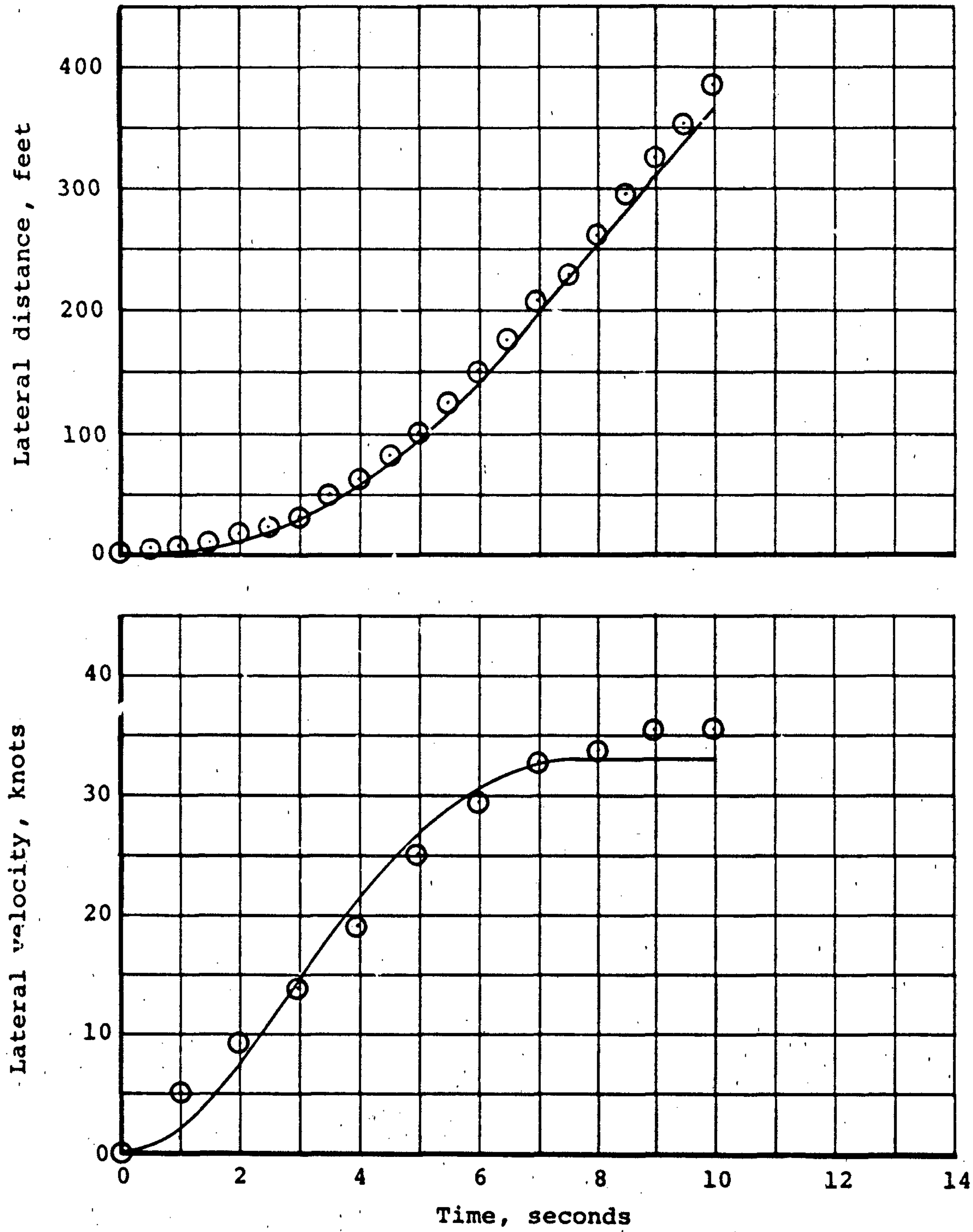

Figure 11. (Continued.)

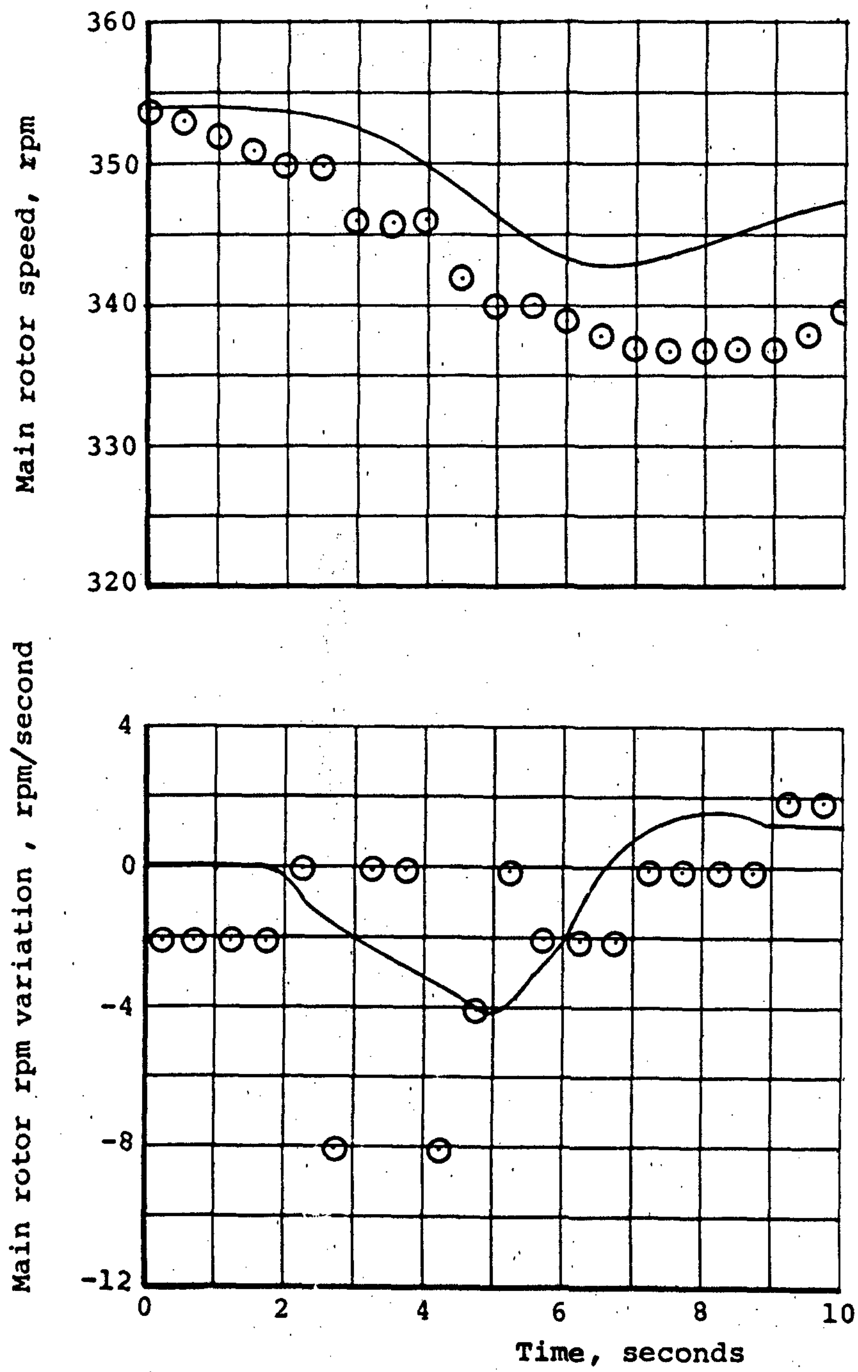

Figure 11. (Continued.)

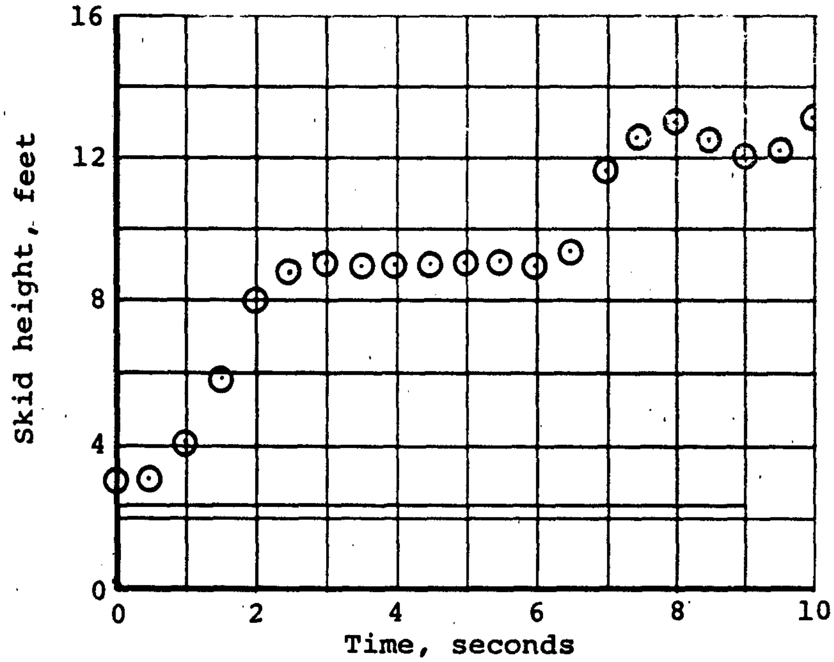

Figure 11. (Concluded.)

REFERENCES

1. Hayden, James S., THE EFFECT OF THE GROUND ON HELICOPTER HOVERING POWER REQUIRED, 32nd Annual National V/STOL Forum of the American Helicopter Society, Washington, D. C., May 1976.

2. Wood, T. L., Ford, D. G., and Brigman, G. H., Bell Helicopter Company; MANEUVER CRITERIA EVALUATION PROGRAM, USAAMRDL Technical Report 74-32, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1974, AD 782209.

3. Dooley, L. W. and Yeary, R. D., Bell Helicopter Textron; FLIGHT TEST EVALUATION OF THE HIGH INERTIA ROTOR SYSTEM, USARTL Technical Report 79-9, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia.

APPENDIX A

USER's GUIDE

INTRODUCTION

The required input data for the MCEP are listed below. The program required a set of basic data that describe the helicopter to be evaluated. The helicopter data are followed by the necessary information for histograms of power, altitude, velocity, and load factor. If a wing is used, then the wing data cards are required. These cards are followed by any number of manuever sets consisting of a maneuver identification card and maneuver data cards. The data are input fields of G10.0, with the exception of the logic variables that have a field of L1.

MCEP can be used to run multiple cases, to simulate complete mission profiles, make parameter sweeps, create a flight path output tape, print selected cases from the output tape, delete selected cases from the output tape, and to plot flight paths. To run multiple cases, simply stack complete data decks. Parameter sweeps can be accomplished without repeating an entire deck. Any of the input variables can be changed via the NAMELIST option by adding the NAMELIST card or cards and the appropriate maneuver cards to the end of the basic data deck. By using the NAMELIST option, the previous basic data deck will be used with only the variables specified on the NAMELIST card(s) changed. The first card of this group must have column 1 blank and &CHANGE in columns 2 to 8. The data items are next and are separated by commas. The NAMELIST card or cards must end with &END, and if continued onto several cards, then each card must have column 1 blank. An example of a NAMELIST change followed by a manuever specification using this change (with column numbers identified) follows:

```
                     1111111111222222222233333333334
COLUMN        : 1234567890123456789012345678901234567890l
NAMELIST      :  &CHANGE PHMAX= 1134., H =1. &END
MANEUVER      : M14
SPECIFICATION: 10.       1.         0.8        1.        9
```

The creation of a flight path output tape is controlled by the variable TAPE on card 13. The first eight characters of the first title card are the identifying name of the maneuver. The next eight spaces are reserved for the date, which is computer generated. The three title cards are written on the tape, preceding the maneuver flight path. Whenever a flight

path tape is used, an index of all the maneuvers on the tape is generated.

The number of files required for a job will depend on the options chosen. Up to nine sequential files may be required. An input tape (FT01F001) is required for adding maneuver flight paths to tape. An input tape is a previously generated output tape. An output tape (FT02F001) stores the flight path information. If an output tape is generated without an input tape, FT01F001 may be declared DUMMY. The basic data deck is input on FT05F001 and the printed output is on FT06F001. Three files (FT08F001, FT09F001, and FT10F001) are used for intermediate storage and are deleted at the end of the job. The index of maneuvers on FT01F001 or FT02F001 is on FT11F001 and should be printed following the print of FT06F001. A plot tape (PLOTTAPE) is required for Calcomp plots. If no plots are produced, files FT08F001, FT09F001, and PLOTTAPE may be dummy files. If no maneuver tapes are to be read or written, files FT01F001, FT02F001, and FT11F001 may be dummy files. Files FT05F001, FT06F001, and FT10F001 are always required.

INPUT FOR BASIC DATA DECK

Identification

Card 01

Columns 1-8	Member name for tape	
9-16	Reserved for date (inserted by program)	
17-72	Identifying comments	

Card 02

Columns 1-72	Identifying comments	

Card 03

Columns 1-72	Identifying comments	

Rotor Group

Card 04

Columns 1-10	Number of rotor blades, B	-
11-20	Rotor chord, C	ft
21-30	Rotor radius, R	ft
31-40	Main rotor induced velocity factor, K3	-
41-50	Tip speed, WR	ft/sec
51-60	Blade section lift curve slope, A2D	/rad
61-70	Constant part of blade C_D, DELO ($C_D = \delta_0 + \delta_1\alpha + \delta_2\alpha^2$)	

The main rotor induced velocity factor, K3, represents the increased induced velocity at low airspeeds to improve correlation with measured data (Reference 1, pages 16, 45, and 47).

Card 05

Columns 1-10	α varying part of blade C_D, DEL1 ($C_D = \delta_0 + \delta_1\alpha + \delta_2\alpha^2$)	/rad
11-20	α^2 varying part of blade C_D, DEL2 ($C_D = \delta_0 + \delta_1\alpha + \delta_2\alpha^2$)	/rad^2
21-30	Drag divergence Mach number, MCRO	-
31-40	Constant in $(t_c)_{Div}$ expression, TC1	-

Card 05 (concluded)

Columns	41-50	Velocity constant in $(t_c)_{Div}$ expression, TC2	-
	51-60	Constant in $t_{c_{max}}$, TCM1	-
	61-70	Velocity constant in $t_{c_{max}}$, TCM2	-

Card 06

Columns	1-10	Ground effect constant (a zero (0) or a one (1) defaults to 0.9926, GEFFZA)	-
	11-20	Ground effect constant, coefficient of Z/D term (a zero (0) defaults to 0.03794, GEFFZB)	-
	21-30	Vertical distance from the bottom of the landing gear to the main rotor pitch change axis (zero turns off ground effect, a positive number applies ground effect to rotor-induced power only, and a negative number applies ground effect to total power), SKTPCA	
	31-40	Efficiency factor for computing climb and descent power ($HP_{V_Z} = -gwV_{ZE}/550\ HP_{EFF}$), HPEFF	-

Fuselage Group

Card 07

Columns	1-10	Flat plate drag (C_D=1) area at β=0°, FO	ft^2
	11-20	Flat plate drag (C_D=1) area at β=90°, F1	ft^2
	21-30	Fuselage angle-of-attack coefficient, KAF1	$\frac{(ft/sec)^{1.6}}{(ft^2\text{-}lb)^{.5}}$
	31-40	Fuselage angle-of-attack coefficient, KAF2	$1/g^2$
	41-50	Fuselage angle-of-attack coefficient, KAF3	$1/g$
	51-60	Fuselage angle-of-attack coefficient, KAF4	$\frac{(ft^2\text{-}lb)^{.5}}{(ft/sec)^{1.6}}$
	61-70	Fuselage angle-of-attack coefficient, KAF5	sec/ft

Card 08

Columns	1-10	Fuselage angle-of-attack coefficient, KAF6	-
	11-20	Fuselage angle-of-attack coefficient, KAF7	deg
	21-30	Fuselage angle-of-attack coefficient, KAF8	-
	31	Wing = (F no wing T wing	

Wing Group

If WING=F, then the next two wing cards are omitted.

Wing Card 01

Columns	1-10	Wing area, SW	ft^2
	11-20	Wing incidence when n=1, IW	deg
	21-30	Wing induced velocity factor, KW	-
	31-40	Wing aspect ratio, ASR	-
	41-50	Wing drag coefficient at zero angle of attack, CDO	-
	51-60	2-D wing lift curve slope, AL2D	/rad
	61-70	Drag coefficient for flat plate, CDFP	-

Wing Card 02

Columns	1-10	Wing efficiency factor, WEFF	-
	11-20	Rate of change of wing incidence with load factor, DIWDN	deg
	21-30	Coefficient, C_{LMAXP}	
	31-40	Maximum negative lift coefficient, C_{LMAXN}	
	41	WINGPRT = (F suppress wing output data T print wing data	

Performance Limits

Card 09

Columns	1-10	Limit dive velocity, VDL	kn
	11-20	Maximum sideward velocity to right, VMRT	kn
	21-30	Maximum sideward velocity to left, VMLT (negative)	kn

Card 09 (concluded)

Columns 31-40	Maximum time to apply power, TMAX	sec
41-50	Minimum time to apply power, TMIN	sec
51-60	Time constant for gamma, TAUP (time to reach 63% of peak rate)	sec
61-70	Time constant for roll, TAUR (time to reach 63% of peak rate)	sec

Card 10

Columns 1-10	Time constant for chi, TAUY (time to reach 63% of peak rate)	sec
11-20	Maximum gamma rate, ARPMX	deg/sec
21-30	Maximum roll rate, ARRMX	deg/sec
31-40	Maximum chi rate, ARYMX	deg/sec
41-50	Maximum positive gamma, GAMMP	deg
51-60	Maximum negative gamma, GAMMN	deg
61-70	Rate of change of vertical load factor, VJERK	/sec

<u>Flight Conditions</u>

Card 11

Columns 1-10	Gross weight, GW	lb
11-20	Velocity, V	kn
21-30	Altitude, H	ft
31-40	X position in Earth reference, XE	ft
41-50	Y position in Earth reference, YE	ft
51-60	Heading, CHI	deg
61-70	Starting time, T	sec

Card 12

Columns 1-10	Air density, RHO	$slug/ft^3$
11-20	Speed of sound, VS	ft/sec
21-30	Maximum power available, HPMAX	hp

Program Control Variables

Card 13

Columns	1-10	Time increment for integration, DDT	sec
	11-20	Error in angular displacement for gain calculation, EPA	deg
	21-30	Error in angular rate for gain calculation, EPAV	deg/sec
	31-40	Generate output tape (0. = no output tape, 1. = write an output tape), TAPE	-

Card 14

Columns	1-10	Upper limit for power histogram, PMAX(1)	hp
	11-20	Lower limit for power histogram, PMIN(1)	hp
	21-30	Interval size for power histogram, DHIST(1)	hp
	31-40	Upper limit for altitude histogram, PMAX(2)	ft
	41-50	Lower limit for altitude histogram, PMIN(2)	ft
	51-60	Interval size for altitude histogram, DHIST(2)	ft

Card 15

Columns	1-10	Upper limit for velocity histogram, PMAX(3)	kn
	11-20	Lower limit for velocity histogram, PMIN(3)	kn
	21-30	Interval size for velocity histogram, DHIST(3)	kn
	31-40	Upper limit for load factor histogram, PMAX(4)	-
	41-50	Lower limit for load factor histogram, PMIN(4)	-
	51-60	Interval size for load factor histogram, DHIST(4)	-

The maximum number of intervals is limited to 200. If any interval size is set to zero, then histograms are bypassed.

INPUT FOR MANEUVERS

The program reads one maneuver identification card at a time. The maneuver called by the main program then reads the maneuver data card following the maneuver identification card. At the conclusion of the maneuver, the main program then reads the next maneuver identification card.

M01: Cruise

Maneuver Identification Card

Columns 1-3: M01

Maneuver Data Card

Columns		
1-10	X aim point in Earth reference, XAP	ft
11-20	Y aim point in Earth reference, YAP	ft
21-30	Cruise time increment, DTI	sec
31-40	Slant range to aim point, SLANT	ft
41	Multiple of time increment for time history output, MPRINT	-

If the aircraft is flying away from the aim point on entry into the cruise maneuver, the maneuver is terminated with a message to that effect. MPRINT controls the frequency of the time history output. Data are printed every MPRINT times the time increment. MPRINT may have values between 0 and 9. An MPRINT value of 0 or 1 prints every time point.

M02: Acceleration/Deceleration

Maneuver Identification Card

Columns 1-3: M02

Maneuver Data Card

Columns		
1-10	Command velocity, VCP	kn
11-20	Velocity error band, VERR	kn
21-30	Maneuver urgency factor, MUF	-
31-40	Minimum power setting, PSL	-
41-50	Maximum power setting, PSU	-
51	Multiple of time increment for time history output, MPRINT	-

M03: Turn at Constant Airspeed and Altitude

Maneuver Identification Card

Columns 1-3: M03

Maneuver Data Card

Columns	1-10	Desired load factor, ND	-
	11-20	Heading, HDG	deg
	21-30	Maneuver urgency factor, MUF	-
	31-40	Delta heading, HDCG	deg
	41-50	Direction of turn, ITURN	-
	51	Multiple of time increment for time history output, MPRINT	-

The turn maneuver can be used to turn to an absolute heading or a delta heading from the aircraft's present heading. If HDG=0 and HDCG=0, the aircraft will turn to 0 degree heading. If HDG=0 and HDCG≠0, then aircraft will turn to present heading plus HDCG. If ITURN>0, a right turn is executed. If ITURN<0, a left turn is executed. If ITURN=0, a minimum heading change turn is executed.

M04: Climb/Descent at Constant Airspeed

Maneuver Identification Card

Columns 1-3: M04

Maneuver Data Card

Columns	1-10	Command altitude, HC	ft
	11-20	Maneuver urgency factor, MUF	-
	21-30	Minimum power setting, PSL	-
	31-40	Command flight path angle, GAMC	deg
	41-50	Maximum load factor, NMAX	-
	51-60	Minimum load factor, NMIN	-
	61	Multiple of time increment for time history output, MPRINT	-

If GAMC=0, the controller computes the appropriate flight path angle based on either MUF or PSL. If GAMC≠0, the controller checks to see if it is possible to maintain airspeed at this flight path angle. If not, the controller resets the flight path angle to the maximum allowed to maintain airspeed.

M05: Pullup/Pushover at Desired Load Factor

Maneuver Identification Card

Columns 1-3: M05

Maneuver Data Card

Columns	1-10	Desired load factor ND	-
	11-20	Maximum load factor, NMAX	-
	21-30	Minimum load factor, NMIN	-
	31-40	Minimum power setting, PSL	-
	41-50	Time to achieve desired load factor, TPP	sec
	51-60	Time to hold desired load factor, TH	sec
	61-70	Minimum velocity, VMIN	kn
	71	Multiple of time increment for time history output, MPRINT	-

M06: Auto Turn at Constant Airspeed

Maneuver Identification Card

Columns 1-3: M06

Maneuver Data Card

Columns	1-10	Desired load factor, ND	-
	11-20	Maneuver urgency factor, MUF	-
	21-30	X aim point in Earth reference, XAP	ft
	31-40	Y aim point in Earth reference, YAP	ft
	41	Multiple of time increment for time history output, MPRINT	-

M07: Return to Target at Constant Altitude

Maneuver Identification Card

Columns 1-3: M07

Maneuver Data Card

Columns	1-10	Desired load factor, ND	-
	11-20	Time to peak roll rate for roll in, TPR	sec
	21-30	Maneuver urgency factor, MUF	-
	31-40	X location of target in Earth reference, TARX	ft

Maneuver Data Card (concluded)

Columns	41-50	Y location of target in Earth reference, TARY	ft
	51-60	Minimum velocity, VMIN	kn
	61-70	Direction of turn, TURN	-
	71	Multiple of time increment for time history output, MPRINT	-

If TURN>0, a right roll occurs. If TURN<0, a left roll occurs. If TURN=0, a minimum heading change occurs.

M08: Dive/Rolling Pullout

Maneuver Identification Card

Columns 1-3: M08

Maneuver Data Card

Columns	1-10	Desired load factor, ND	-
	11-20	Desired dive angle, GAMCR	deg
	21-30	X location of target in Earth reference, TARX	ft
	31-40	Y location of target in Earth reference, TARY	ft
	41-50	Z location of target in Earth reference, TARZ	ft
	51-60	Minimum slant range to target, SLANT	ft
	61-70	Delta heading, DHDG	deg

Maneuver Data Card

Columns	1-10	Maximum load factor, NMAX	-
	11-20	Minimum load factor, NMIN	-
	21-30	Minimum velocity, VMIN	kn
	31-40	Maneuver urgency factor for dive, MUFD	-
	41-50	Maneuver urgency factor for roll, MUFR	-
	51-60	Minimum power setting, PSL	-
	61	Multiple of time increment for time history output, MPRINT	-

The sign of DHDG determines the sign of the bank angle. If GAMCR=0, the controller computes the required dive angle to intersect the target.

M09: Climbing/Descending Turn at Constant Airspeed

Maneuver Identification Card

Columns 1-3: M09

Maneuver Data Card

Columns	1-10	Command altitude, HC	ft
	11-20	Desired load factor, ND	-
	21-30	Desired heading, HDG	deg
	31-40	Maneuver urgency factor, MUF	-
	41-50	Minimum power setting, PSL	-
	51-60	Maximum load factor, NMAX	-
	61-70	Minimum load factor, NMIN	-
	71	Multiple of time increment for time history output, MPRINT	-

If ND=0, the controller selects the flight path angle and bank angle. If ND≠0, the controller uses the remaining power available to compute the flight path angle.

M10: Sideward Acceleration/Deceleration

Maneuver Identification Card

Columns 1-3: M10

Maneuver Data Card

Columns	1-10	Command bank angle, PHIC	deg
	11-20	Command velocity, VCRAB	kn
	21-30	Maneuver urgency factor, MUF	-
	31-40	Power required for tail rotor, HPMTR	hp
	41-50	X location of target in Earth reference, TARX	ft
	51-60	Y location of target in Earth reference, TARY	ft
	61	Multiple of time increment for time history output, MPRINT	-

M11: Sideward Acceleration/Pedal Turn Into Wind

Maneuver Identification Card

Columns 1-3: M11

Maneuver Data Card

Columns	1-10	Command bank angle, PHIC	deg
	11-20	Command velocity, VCRAB	kn
	21-30	Maneuver urgency factor, MUF	-
	31-40	Power required to tail rotor, HPMTR	hp
	41-50	X location of target in Earth reference, TARX	ft
	51-60	Y location of target in Earth reference, TARY	ft
	61-70	Time to peak $\dot{\beta}$, TPY	sec

Maneuver Data Card

Columns	1-10	Desired $\dot{\beta}$, BETAD	deg/sec
	11-20	Cruise time at VC and steady state bank angle, TCRUSE	sec
	21	Multiple of time increment for time history output, MPRINT	-

M12: Orbit at Constant Airspeed

Maneuver Identification Card

Columns 1-3: M12

Maneuver Data Card

Columns	1-10	Turn radius, RADIUS	ft
	11-20	Exit heading, HDG	deg
	21-30	Maneuver urgency factor, MUF	-
	31-40	Time of orbit, TORBIT	sec
	41-50	Direction of turn, PHIDR	-
	51	Multiple of time increment for time history output, MPRINT	-

M13: Pedal Turn at Hover

Maneuver Identification Card

Columns 1-3: M13

Maneuver Data Card

Columns	1-10	Desired heading, HDG	deg
	11-20	Time to peak rate of change of heading, TPY	sec
	21-30	Desired rate of change of heading, CHIDR	deg/sec

Maneuver Data Card (concluded)

Columns	31	Multiple o. time increment for time history output, MPRINT	-

M14: Collective Pop-Up at Constant Attitude and Low Airspeed

Maneuver Identification Card

Columns 1-3: M14

Maneuver Data Card

Columns	1-10	Command altitude, HC	ft
	11-20	Maneuver urgency factor, MUF	-
	21-30	Minimum load factor, NMIN	-
	31-40	Maximum power setting, PSU	-
	41	Multiple of time increment for time history output, MPRINT	-

M15: Climbi.ng Return to Target

Maneuver Identification Card

Columns 1-3: M15

Maneuver Data Card

Columns	1-10	Command altitude, HC	ft
	11-20	X location of target in Earth reference, TARX	ft
	21-30	Y location of target in Earth reference, TARY	ft
	31-40	Z location of target in Earth reference, TARZ	ft
	41-50	Maximum load factor, NMAX	-
	51-60	Minimum load factor, NMIN	-
	61-70	Command bank angle, PHIC	deg

Maneuver Data Card

Columns	1-10	Command climb angle, GAMC	deg
	11-20	Minimum velocity, VMIN	kn
	21-30	Time to peak rate for rollout, TPPOUT	sec
	31-40	Time to peak γ, TPP	sec
	41-50	Time to peak ϕ, TPR	sec
	51-60	Minimum power setting, PSL	-
	61-70	Time to apply full power, TACCEL	sec
	71	Multiple of time increment for time history output, MPRINT	-

M16: Acceleration Using Bleed RPM

Maneuver Identification Card

Columns 1-3: M16

Maneuver Data Card

Columns	1-10	Command velocity, VCP	kn
	11-20	Velocity error band, VERR	kn
	21-30	Maneuver urgency factor MUF	-
	31-40	Minimum power setting, PSL	-
	41-50	Maximum power setting, PSU	-
	51	Multiple of time increment for time history output, MPRINT	-

Maneuver Data Card

Columns	1-10	Blade inertia, BINERT	$slug\text{-}ft^2$
	11-20	Main rotor transmission rating, HPMAXT	hp
	21-30	Energy efficiency factor, EEF	
	31-40	Minimum rotor rpm, OMEGMN	rpm
	41-50	Time interval to accelerate at minimum rpm, TRPMMN	sec
	51-60	Continue acceleration at minimum rpm until this velocity is reached, VMNREC	kn

Maneuver Data Card

Columns	1-10	1st bleed rate of rotor rpm, OMGBD1	rpm/sec
	11-20	Rotor rpm breakpoint for changing bleed rate, OMGBL2	rpm
	21-30	2nd bleed rate of rotor rpm, OMGBD2	rpm/sec
	31-40	Rotor rpm breakpoint for changing bleed rate, OMGBL3	rpm
	41-50	3rd bleed rate of rotor rpm, OMGBD3	rpm/sec
	51-60	Rotor rpm breakpoint for changing bleed rate, OMGBL4	rpm
	61-70	4th bleed rate of rotor rpm, OMGBD4	rpm/sec

Maneuver Data Card

Columns	1-10	1st recovery rate of rotor rpm, OMGRD1	rpm/sec
	11-20	Rotor rpm breakpoint for changing recovery rate, OMGRC2	rpm
	21-30	2nd recovery rate of rotor rpm, OMGRD2	rpm/sec
	31-40	Rotor rpm breakpoint for changing recovery rate, OMGRC3	rpm
	41-50	3rd recovery rate of rotor rpm, OMGRD3	rpm/sec
	51-60	Rotor rpm breakpoint for changing recovery rate, OMGRC4	rpm
	61-70	4th recovery rate of rotor rpm, OMGRD4	rpm/sec

This maneuver will accelerate using rotational energy from the rotor system to supplement the engine and then recover the lost rotor rpm. Once the rotor has reached the minimum rpm, the acceleration will continue for TRPMMN seconds and until VMNREC knots is reached before the recovery phase is initiated. As the command velocity VCP is approached, the recovery phase will begin (if any rpm has been bled). From one to four bleed rpm rates can be specified, and from one to four recovery rpm rates can be specified independently. All rpm rates are input as positive numbers.

M17: Collective Pop-Up Using Bleed RPM at Constant Attitude And Low Airspeed

Maneuver Identification Card

Columns 1-3: M17

Maneuver Data Card

Columns	1-10	Command altitude, HC	ft
	11-20	Maneuver urgency factor, MUF	-
	21-30	Minimum load factor, NMIN	-
	31-40	Maximum power setting, PSU	-
	41	Multiple of time increment for time history output, MPRINT	

Maneuver Data Card

Columns	1-10	Blade inertia, BINERT	$slug\text{-}ft^2$
	11-20	Main rotor transmission rating, HPMAXT	hp
	21-30	Energy efficiency factor, EEF	-

Maneuver Data Card (concluded)

Columns	31-40	Minimum rotor rpm, OMEGMN	rpm
	41-50	Maximum load factor during pullout if aircraft descends, NMAXDV	-

Maneuver Data Card

Columns	1-10	1st bleed rate of rotor rpm, OMGBD1	rpm/sec
	11-20	Rotor rpm breakpoint for changing bleed rate, OMGBL2	rpm
	21-30	2nd bleed rate of rotor rpm, OMGBD2	rpm/sec
	31-40	Rotor rpm breakpoint for chang-bleed rate, OMGBL3	rpm
	41-50	3rd bleed rate of rotor rpm, OMGBD3	rpm/sec
	51-60	Rotor rpm breakpoint for chang-bleed rate, OMGBL4	rpm/sec
	61-70	4th bleed rate of rotor rpm, OMGBD4	rpm/sec

Maneuver Data Card

Columns	1-10	1st recovery rate of rotor rpm, OMGRD1	rpm/sec
	11-20	Rotor rpm breakpoint for changing recovery rate, OMGRC2	rpm
	21-30	2nd recovery rate of rotor rpm, OMGRD2	rpm/sec
	31-40	Rotor rpm breakpoint for changing recovery rate, OMGRC3	rpm
	41-50	3rd recovery rate of rotor rpm, OMGRD3	rpm/sec
	51-60	Rotor rpm breakpoint for changing recovery rate, OMGRC4	rpm
	61-70	4th recovery rate of rotor rpm, OMGRD4	rpm/sec

This maneuver will climb using inertial energy from the rotor system to supplement the engine and then recover the lost rotor rpm. As the command altitude HC is approached, the recovery phase will begin (if any rpm has been bled). From one to four bleed rpm rates can be specified, and from one to four recovery rpm rates can be specified independently. If a recovery rate of zero is specified for a breakpoint, the recovery rate will be the maximum rate allowed by the engine and transmission. All rpm rates are input as positive numbers.

M18: Sideward Acceleration Using Bleed RPM/Pedal Turn Into Wind

Maneuver Identification Card

Columns 1-3: M18

Maneuver Data Card

Columns		
1-10	Command bank angle, PHIC	deg
11-20	Command velocity, VCRAB	kn
21-30	Maneuver urgency factor, MUF	-
31-40	Power required to tail rotor, HPMTR	hp
41-50	X location of target in Earth reference, TARX	ft
51-60	Y location of target in Earth reference, TARY	ft
61-70	Time to peak β, TPY	sec

Maneuver Data Card

Columns		
1-10	Desired β, BETAD	deg/sec
11-20	Cruise time at VC and steady state bank angle, TCRUSE	sec
21	Multiple of time increment for time history output, MPRINT	-

Maneuver Data Card

Columns		
1-10	Blade inertia, BINERT	slug-ft^2
11-20	Main rotor transmission rating, HPMAXT	hp
21-30	Energy efficiency factor, EEF	-
31-40	Minimum rotor RPM, OMEGMN	rpm
41-50	Time to peak bleed rate, TBLED	sec
51-60	Maximum bleed rate allowed, OMGDMX	rpm/sec

This maneuver will accelerate sidewards using inertial energy from the rotor system to supplement the engine and then recover the lost rotor rpm before the pedal turn. As the command velocity VC is approached, the recovery phase will begin (if any rpm has been bled). The rpm rate is input as a positive number.

M19: Terrain Avoidance Maneuver (Pullup/Pushover)

Maneuver Identification Card

Columns 1-3: M19

Maneuver Data Card

Columns	1-10	Time points for specified load factors and horsepower supplied from the engine, TI(1)	sec
	11-20	TI(2)	sec
	21-30	TI(3)	sec
	31-40	TI(4)	sec
	41-50	TI(5)	sec
	51-60	TI(6)	sec
	61-70	TI(7)	sec

Maneuver Data Card

Columns	1-10	TI(8)	sec
	11-20	TI(9)	sec
	21-30	TI(10)	sec
	31-40	TI(11)	sec
	41-50	TI(12)	sec
	51-60	TI(13)	sec
	61-70	TI(14)	sec

Maneuver Data Card

Columns	1-10	TI(15)	sec
	11-20	TI(16)	sec
	21-30	TI(17)	sec
	31-40	TI(18)	sec
	41-50	TI(19)	sec
	51-60	TI(20)	sec
	61-70	TI(21)	sec

Maneuver Data Card

Columns	1-10	Load factors corresponding to the specified time points, NI(1)	-
	11-20	NI(2)	-
	21-30	NI(3)	-
	31-40	NI(4)	-
	41-50	NI(5)	-
	51-60	NI(6)	-
	61-70	NI(7)	-

Maneuver Data Card

Columns	1-10	NI(8)	-
	11-20	NI(9)	-
	21-30	NI(10)	-
	31-40	NI(11)	-
	41-50	NI(12)	-

Maneuver Data Card

Columns	51-60	NI(13)	-
	61-70	NI(14)	-

Maneuver Data Card

Columns	1-10	NI(15)	-
	11-20	NI(16)	-
	21-30	NI(17)	-
	31-40	NI(18)	-
	41-50	NI(19)	-
	51-60	NI(20)	-
	61-70	NI(21)	-

Maneuver Data Card

Columns	1-10	Horsepower supplied from the engine, HPAI(1)	hp
	11-20	HPAI(2)	hp
	21-30	HPAI(3)	hp
	31-40	HPAI(4)	hp
	41-50	HPAI(5)	hp
	51-60	HPAI(6)	hp
	61-70	HPAI(7)	hp

Maneuver Data Card

Columns	1-10	HPAI(8)	hp
	11-20	HPAI(9)	hp
	21-30	HPAI(10)	hp
	31-40	HPAI(11)	hp
	41-50	HPAI(12)	hp
	51-60	HPAI(13)	hp
	61-70	HPAI(14)	hp

Maneuver Data Card

Columns	1-10	HPAI(15)	hp
	11-20	HPAI(16)	hp
	21-30	HPAI(17)	hp
	31-40	HPAI(18)	hp
	41-50	HPAI(19)	hp
	51-60	HPAI(20)	hp
	61-70	HPAI(21)	hp

Maneuver Data Card

Columns	1-10	Minimum power setting, PSL	-
	11	Multiple of time increment for time history output, MPRINT	-

This maneuver will force the helicopter to have the specified load factors and engine supplied horsepower at the specified times. If the engine horsepower is specified as zero (HPAI=0), the procedure computes the engine horsepower as the horsepower required for the maneuver and is limited by HPMAX and HPMIN (PSL*HPMAX). From one to twenty-one points may be specified. If TI(1)≠0, the maneuver will start at T=0 and load factor=1. Horsepower is computed between T=0 and the TI(1) specified. Between specified time points, the load factor N and horsepower HPA (if specified) are linearly interpolated.

M20: Speed Power Polar

Maneuver Identification Card

Columns	1-10	Minimum velocity on plot, ENDPT(1)	kn
	11-20	Maximum velocity on plot, ENDPT(2)	kn
	21-30	Minimum horsepower on plot, ENDPT(3)	hp
	31-40	Maximum horsepower on plot, ENDPT(4)	hp
	41	Plot symbol for HPTOTAL, PLTCHR(1)	-

Maneuver Data Card

Columns	42	Plot symbol for HP1, PLTCHR(2)	-
	43	Plot symbol for HP2, PLTCHR(3)	-
	44	Plot symbol for HP3, PLTCHR(4)	-
	45	Plot symbol for HP4, PLTCHR(5)	-
	46	Plot symbol for HP5, PLTCHR(6)	-
	47	Plot symbol for HP6, PLTCHR(7)	-
	48	Plot symbol for HP7, PLTCHR(8)	-
	49	Plot symbol for HPS, PLTCHR(9)	

Maneuver Data Card

Columns	1-10	Initial speed for speed power polar, VO	kn
	11-20	Final speed for speed power polar, VFN	kn
	21-30	Speed increment for speed power polar, DELV	kn

Maneuver Data Card (Concluded)

Columns	31-40	Initial load factor for sweep, NO	-
	41-50	Final load factor for sweep, NFN	-
	51-60	Load factor increment for sweep, DELN	-
	61-70	Initial gross weight for sweep, GWO	-

Maneuver Data Card

Columns	1-10	Final gross weight for sweep, GWFN	lb
	11-20	Gross weight increment for sweep, DELGW	lb

This maneuver computes and plots the horsepower versus speed function while sweeping the load factor and gross weight. The velocity and horsepower plot ranges will apply to all the speed power polars generated in the sweep. If the velocity and/or horsepower plot ranges are zero, the plot range will be computed for each speed power polar in the sweep. Any plot symbols left blank will default. The default values of the nine plot symbols are T1234567S. If the final load factor (/gross weight) is less than the initial load factor (/gross weight), just one speed power polar will be generated for the initial load factor (/gross weight).

INPUT FOR COMMAND CARDS

This section describes the command cards. There are three command cards - /PLOT, /PRINT, /DELETE. The MEMBER NAME referred to on the command cards references the first eight characters of the first title card of each flight path.

The /PLOT card can refer to a currently generated flight path, a flight path written on the output tape or a flight path on the input tape. In general, the /PRINT, /PLOT, /DELETE, and restart data decks may occur in any order and there may be a maximum of 100 cards each of the /command cards. The one exception is when the maneuver output for a data deck is not written on tape and it is desired to plot the maneuver. Then the /PLOT card or cards naming the desired maneuver must precede the data deck. The same maneuver name may appear on more than one /PLOT card.

PLOT

Card 1

Col. 1-5	/PLOT
Col. 9-16	MEMBER NAME (left justified)
Col. 17-18	Blank if X and Y increments are to be chosen separately on the isometric plot. "XY" if X and Y increments are to be equal on the isometric plot.
Col. 19	Blank if the Z increment is to be independently chosen on the isometric plot. "Z" if the Z increment is to equal the maximum of the X,Y,Z increments of the isometric plot.
Col. 20	Blank if rest of information on the card is not to be used. Nonblank and not "T" (such as "F") if the rest of the information on the card is to be used, but no maximum and minimum information is provided. "T" if the rest of the information on the card is to be used and CARD 2 with maximum and minimum information is provided.

The format for the rest of the card is 6F10.0.

Col. 21-30	Angle of rotation in X-Y plane (in degrees, positive counterclockwise); alpha.
Col. 31-40	Angle of rotation in plane of plot paper (in degrees, positive counterclockwise); beta.
Col. 41-50	Angle of rotation in new Y-Z plane (in degrees, positive counterclockwise); gamma.

```
     Col. 51-60  Scaling factor for plot.
     Col. 61-70  Translation of X axis of plot.
     Col. 71-80  Translation of Y axis of plot.
```

Card 2

```
     Col.  1-10  Maximum value of X to be plotted.
     Col. 11-20  Minimum value of X to be plotted.
     Col. 21-30  Maximum value of Y to be plotted.
     Col. 31-40  Minimum value of Y to be plotted.
     Col. 41-50  Maximum value of Z to be plotted.
     Col. 51-60  Minimum value of Z to be plotted.
```

If only the MEMBER NAME is specified on the /PLOT card, the default of three plots is produced. For these three plots the scaling factor is one, no translation is performed and the maximum and minimum values of X, Y, Z are computer selected. The first plot is a view of the X-Z plane (alpha=0., beta=0., gamma=0.) looking in a negative Y direction. The second plot is a view of the X-Y plane (alpha=0., beta=0., gamma=90.) looking in a negative Z direction. The third plot is an isometric view from the fourth quadrant of the upper hemisphere (alpha=4., beta=0., gamma=1.).

A single plot can be produced using card 1 by specifying any of the plot parameters from column 20 to the end. If the scaling factor is zero, it defaults to the value 1. The angles alpha and gamma determine the point of reference of the plot. Alpha is the angle of rotation in the X-Y plane, and gamma the angle of rotation in the Y-Z plane. Beta is a rotation in the plane of the plot paper.

An isometric plot is specified by the value of gamma. Gamma equal to ±1. refers to the upper or lower hemisphere respectively. Alpha specifies the quadrant; the permissible values of alpha are 1., 2., 3., 4. As before, beta specifies a rotation in the plane of the plot. Some examples of the plot cards (with column numbers identified) follows:

```
                         1111111111222222222233333333334444
COLUMN      :  1234567890123456789012345678901234567890123 4
3 PLOTS:    :  /PLOT    PLOTTEST
SINGLE PLOT:   /PLOT    PLOTTEST    F45.         0.0         45.
SINGLE PLOT:   /PLOT    PLOTTEST    F1.0         0.0         1.0
SINGLE PLOT:   /PLOT    PLOTTEST    F4.0         0.0         -1.0
```

PRINT

```
     Col.  1-6   /PRINT
     Col.  9-16  MEMBER NAME (left justified)
```

This command will print the specified maneuver data from the input tape (or output tape if one is generated).

DELETE

Col. 1-7 /DELETE
Col. 9-16 MEMBER NAME (left justified)

This command will delete a maneuver from the output tape (the specified maneuver is not copied from the input tape to the output tape).

OUTPUT

The printed output (file FT06F001) will first give an annotated listing of all of the input variables in the basic data deck. Next, the individual maneuvers will be printed. Each maneuver output consists of its input data, headings for the flight path variables, the flight path variables, and a summary of the maneuver. When data decks are stacked or variables are changed via the NAMELIST option, the above format is repeated. A message is printed identifying each maneuver group that has been written on tape, deleted from tape, or plotted. The listings of maneuver groups from tape (obtained by /PRINT cards) appear after all data decks have been processed.

The Calcomp plots should be made on plain white paper or 1-inch grid paper. Except for most of the isometric plots, standard 8-1/2 x 11-inch paper can be used. Of the isometric plots, only the default plot (alpha=4., gamma=1.) will fit on the 8-1/2 x 11-inch paper. The other isometric views must be plotted on 30-inch-width paper with a 10-inch offset from the margin.

The flight path output tape has three title cards followed by eight variables (time, x, y, z location, velocity, beta, alpha, and phi angular orientation) for each time point.

LIST OF SYMBOLS

BETAD	Rate of change of sideslip angle with respect to time, deg/sec
BINERT	Blade inertia, slug-ft^2
D	Main rotor diameter, ft
E	Energy stored in rotor, ft-lb
EER	Energy efficiency factor
GEFFZA	Coefficient in-ground-effect equation
GEFFZB	Coefficient in-ground-effect equation
H	Height of the landing gear above the ground, ft
HP	Power required for given condition, hp
HPA	Power available for maneuvering, hp
HPC	Maximum engine power applied, hp
HPAI(I)	Horsepower supplied from the engine corresponding to specified time points, hp
HPENG	Power available from engine for maneuvering, hp
HPLIM	Transmission power rating at normal rpm, hp
HPMTR	Power produced by bleeding rpm, hp
HPEMAX	Maximum engine power available, hp
HPMAXT	Main rotor transmission rating, hp
HPTMAX	Maximum power limit of transmission at current rpm, hp
HPTOTAL	Sum of engine power and power extracted from the rotor, hp
HP_{EXCESS}	Excess power available to recover rpm, hp
IR	Rotational inertia of the rotor system, slug-ft^2

$\frac{K}{K_\infty}$	Ratio applied to either induced or total power correct for ground effect
KR	Energy efficiency factor
MUF	Maneuver urgency factor
MPRINT	Multiple of time increment for time history output
NI(I)	Load factors corresponding to specified time points
NMIN	Minimum load factor
NMAXDV	Maximum load factor during pullout if aircraft descends
OMGBD1	First bleed rate of rotor rpm, rpm/sec
OMGBL2	Rotor rpm breakpoint for changing bleed rate, rpm
OMGRC2	Rotor rpm breakpoints for changing recovery rate
OMGRD1	First recovery rate of rotor rpm, rpm/sec
OMEGMN	Minimum rotor rpm
PSL	Minimum power setting
PSU	Maximum power setting
PHIC	Command bank angle, deg
Q	Torque at instantaneous rpm, ft-lb
Q_{MAX}	Maximum transmission torque, ft-lb
SKTPCA	Height from bottom of landing gear to rotor pitch change axis, ft
TARX	X_E location of target, ft
TARY	Y_E location of target, ft
TBLED	Time to reach peak bleed rate, sec
TCRUSE	Time to cruise at commanded velocity and steady state bank angle, sec

TI(I)	Time points for specified load factors and horsepower supplied from engine, sec
tpn	Time to reach maximum load factor in collective pop-up
TPY	Time to reach peak sideslip velocity, sec
TRPMMN	Time interval to accelerate at minimum rpm, sec
V	Velocity along flight path, ft/sec
VCP	Command velocity in acceleration maneuver using bleed rpm, kn
VCRAB	Commanded sideward velocity, kn
VERR	Velocity error bank, kn
VMNREC	Continue acceleration at minimum rpm until this velocity is reached, kn
V_{ZE}	Components of velocity in Z_E direction, ft/sec
V_{horz}	Horizontal velocity, ft/sec
Z	Height of the main rotor hub above the ground, ft
Z_E	Height above the ground in the earth axis system, ft
ΔHPENG	Increment subtracted from engine power available to prevent overtorquing the transmission, hp
σ'	Density ratio
Ω	Rotor rotational speed, rad/sec or rpm
$\dot{\Omega}$	Ratio of change of rotational speed with respect to time, rad/sec or rpm/sec
ΩMIN	Specified minimum rotation speed, rad/sec or rpm
$\dot{\Omega}$MAX	Specified maximum bleed rate, rad/sec^2 or rpm/sec